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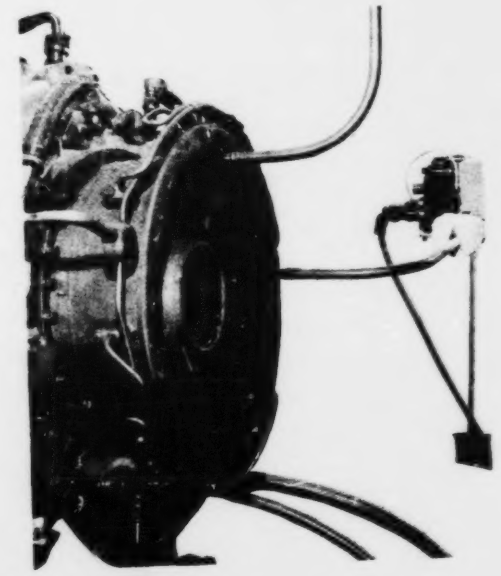
TEST REPORT

EXHAUST EMISSIONS TEST AIRESEARCH AIRCRAFT PROPULSION AND AUXILIARY POWER GAS TURBINE ENGINES



for

ENVIRONMENTAL PROTECTION AGENCY
OFFICE OF AIR PROGRAMS

GT-8747-R

SEPTEMBER 10, 1971

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The report describes the test setup, procedure, and analysis of exhaust emissions measurement conducted on 32 commercial gas turbine engines comprised of both on-board aircraft auxiliary power and aircraft propulsion production, overhaul, and development units. The units selected are currently active in commercial airline service and thus contribute to aircraft related pollution levels. The purpose of this test was to measure exhaust emissions from auxiliary power and small aircraft propulsion gas turbines engines to establish base levels of unburned hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen in current existing engine designs. In addition, a survey of engine duty cycles as related to normal customer operation in the field was made to determine a typical duty cycle and the corresponding estimated level of exhaust emissions produced.

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TEST REPORT

EXHAUST EMISSIONS TEST
AIRESEARCH AIRCRAFT PROPULSION AND AUXILIARY POWER GAS TURBINE ENGINES

GT-8747-R September 10, 1971

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B - EMISSIONS PERFORMANCE DATA REDUCTION PRINTOUT (33 pages)

C - MEASURED AND CALCULATED EMISSIONS PERFORMANCE PLOTTED AS A FUNCTION OF EQUIVALENCE RATIO (75 pages)

D - EXHAUST EMISSIONS STRATIFICATION CURVES (160 pages)

E - FUEL ANALYSIS AND TYPICAL GAS SAMPLING ANALYZER TRACES (5 pages)

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TEST REPORT
EXHAUST EMISSIONS TEST
AIRESEARCH AIRCRAFT PROPULSION AND AUXILIARY POWER GAS TURBINE ENGINES

1. INTRODUCTION

This report describes the test setup, procedure, and analysis of exhaust emissions measurements conducted on 32 AiResearch commercial gas turbine engines comprised of both on-board aircraft auxiliary power and aircraft propulsion production, overhaul, and development units. The units selected are currently active in commercial airline service and thus contribute to aircraft-related pollution levels.

The purpose of this test was to measure exhaust emissions from auxiliary power and small aircraft propulsion gas turbine engines to establish base levels of unburned hydrocarbons, carbon monoxide, carbon dioxide and oxides of nitrogen in current existing engine designs. In addition, a survey of engine duty cycles as related to normal customer operation in the field was made to determine a typical duty cycle and the corresponding estimated level of exhaust emissions produced.

The emissions test program was accomplished under contract 68-04-0022 with the Environmental Protection Agency, Office of Air Programs, (formerly the Air Pollution Control Office, APCO). AiResearch was one of several organizations contracted by the Environmental Protection Agency to conduct gas turbine exhaust emissions measurements. Each organization will submit their evaluation of baseline levels of gas turbine exhaust emissions to assist the Environmental Protection Agency in preparing proposed aircraft emissions standards.

A special acknowledgement is given to the Environmental Protection Agency for providing gas analyzer instrumentation, instruction in their use, and participation in the data accumulation phase of this program.

Measured and calculated exhaust emissions performance is presented in the following summary of test results.

2. SUMMARY

A summary of the exhaust emissions test results for all gas turbine engines tested are expressed as plots of the respective emission indexes for total hydrocarbons, carbon monoxide, and total oxides of nitrogen (expressed as NO_2) followed by a plot showing the percent contribution of the constituents NO and NO_2 in the total oxides of nitrogen, all as a function of equivalence ratio as shown in Figures 1, 2, 3, and 4. Emission index is independent of fuel flow or engine size and is defined as lb pollutant/1000 lb of fuel consumed. Equivalence ratio is defined as the actual fuel-air ratio at the operating condition to the stoichiometric fuel-air ratio for the fuel used. In all cases, the band width of the plot includes all the power settings from the various engine tests and, thus, represents the total variation in the emission characteristics from each class of engine tested. The engines were operated from idle conditions which correspond to the low end of the equivalence ratio scale to the maximum rated shaft horsepower at the higher equivalence ratios. Various combinations of bleed-air and shaft horsepower loads were then applied to the limit of the maximum rated exhaust gas temperatures. The transparent overlays provided represent characteristic emission indexes for single engine tests on the series engines shown over a range of power settings for comparison.

Table 1 presents a tabular comparison of all the measured maximum to minimum emission concentrations for all engine series tested over the entire operating load range. The emissions results for all power settings applicable to a given engine are summarized in the data reduction printout included as Appendix B. These tabulated data are represented in plotted form for each engine in Appendix C as described by the appendix curve index. Section 3. describes each engine model tested within a given series and further explains the alpha/numerical code that describes engines at AiResearch.

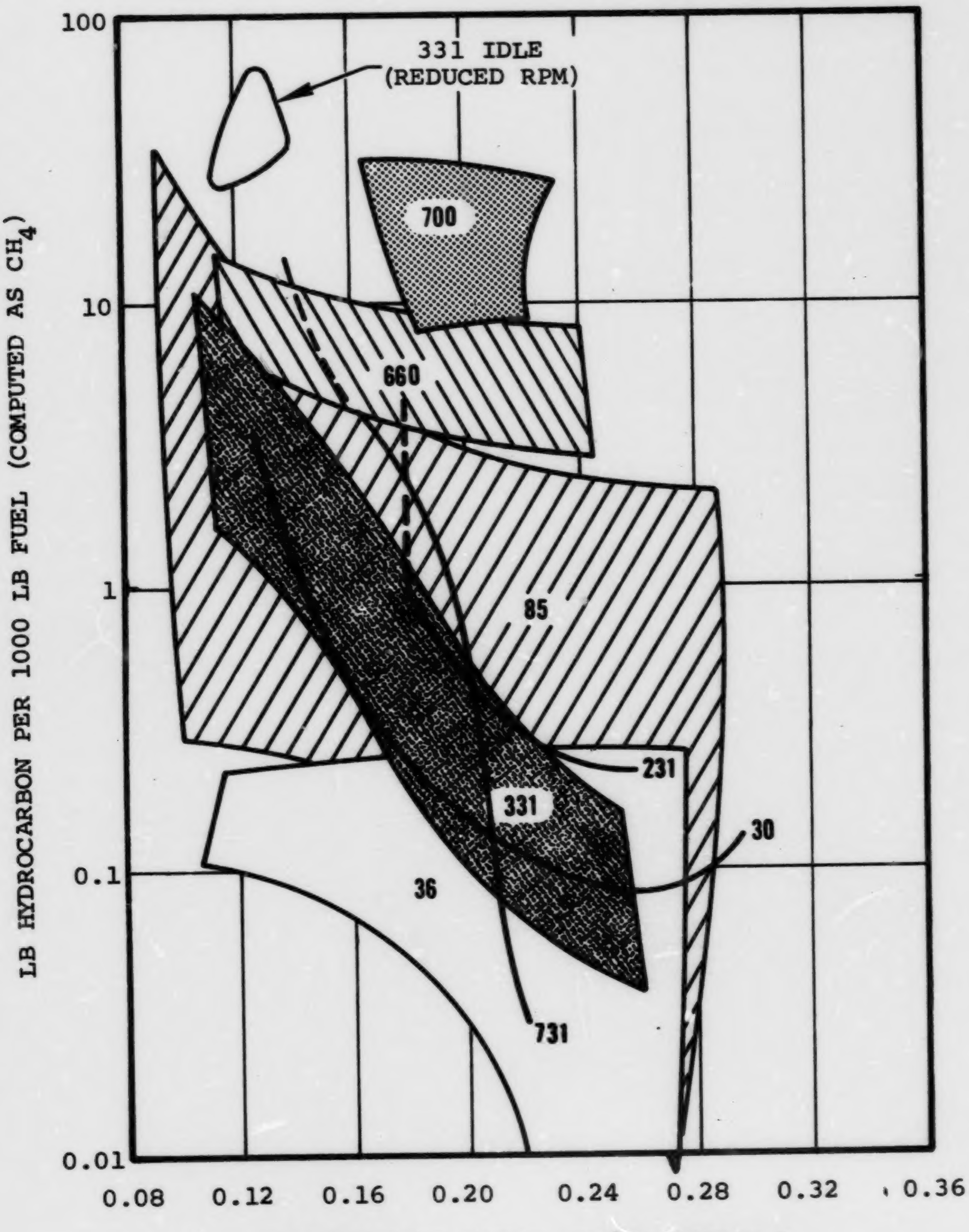
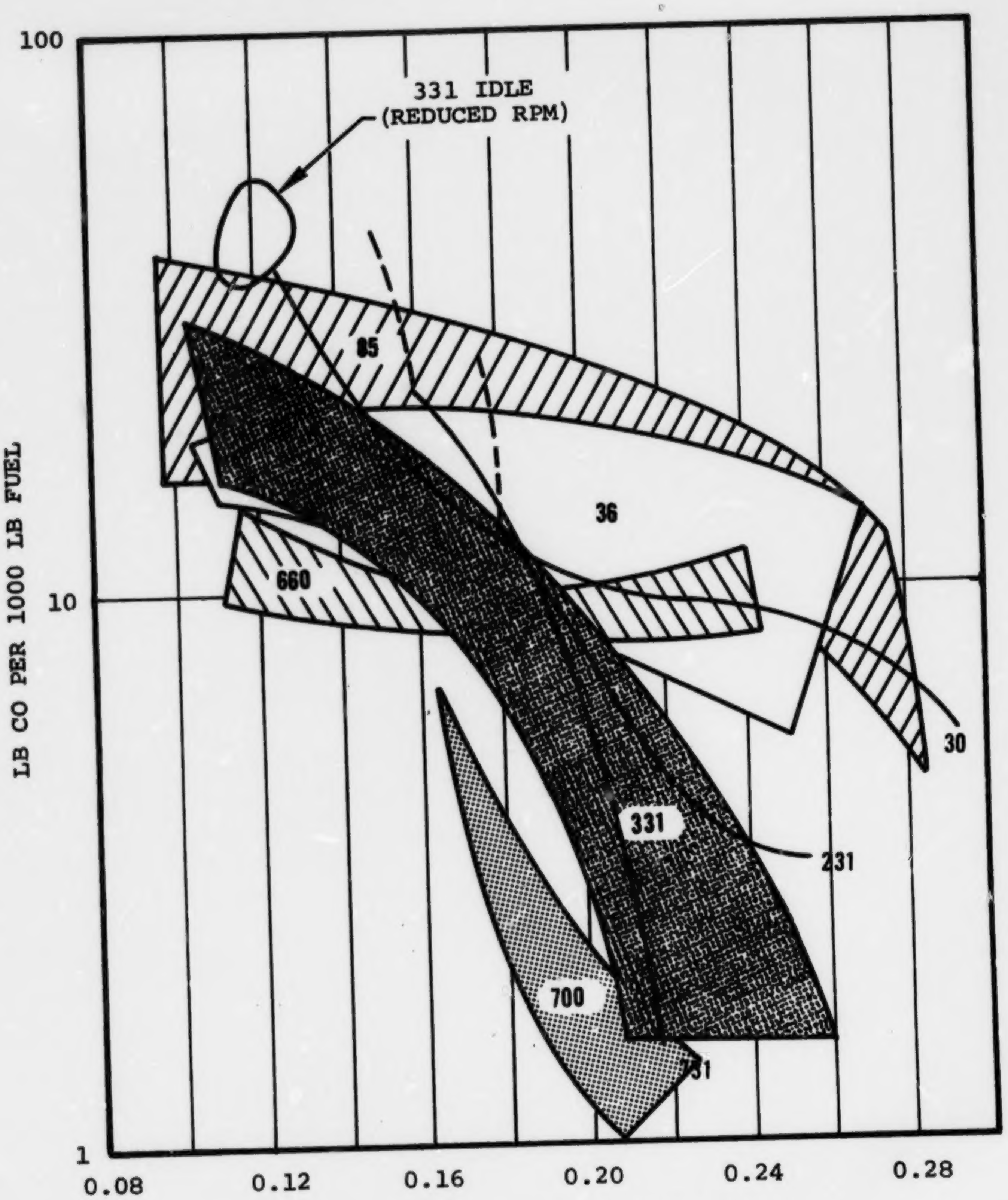

331 IDLE (REDUCED RPM)
700
660
85
231
331
30
36
731
100
10
1
0.1
0.01
0.08
0.12
0.16
0.20
0.24
0.28
0.32
0.36
LB HYDROCARBON PER 1000 LB FUEL (COMPUTED AS CH_4)
EQUIVALENCE RATIO, FA/FA (STOIC.)

FIGURE 1


100
10
1
LB CO PER 1000 LB FUEL
331 IDLE
(REDUCED RPM)
85
36
660
30
331
231
700
731
0.08
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0.16
0.20
0.24
0.28
EQUIVALENCE RATIO, FA/FA (STOIC.)

FIGURE 2

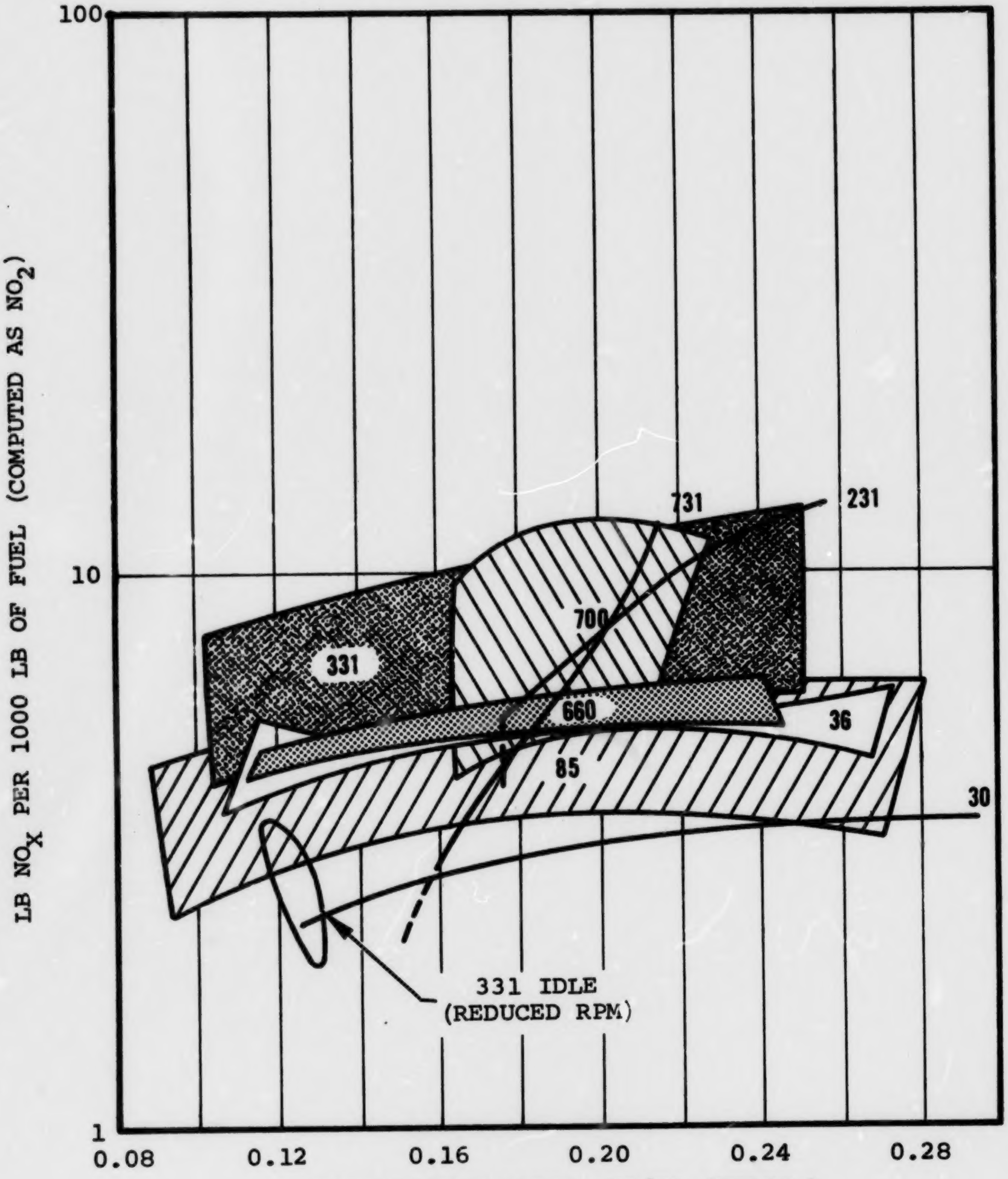
100
10
1
LB NO_X PER 1000 LB OF FUEL (COMPUTED AS NO_2)
0.08
0.12
0.16
0.20
0.24
0.28
EQUIVALENCE RATIO, FA/FA (STOIC.)
731
231
700
331
660
36
85
30
331 IDLE
(REDUCED RPM)

FIGURE 3

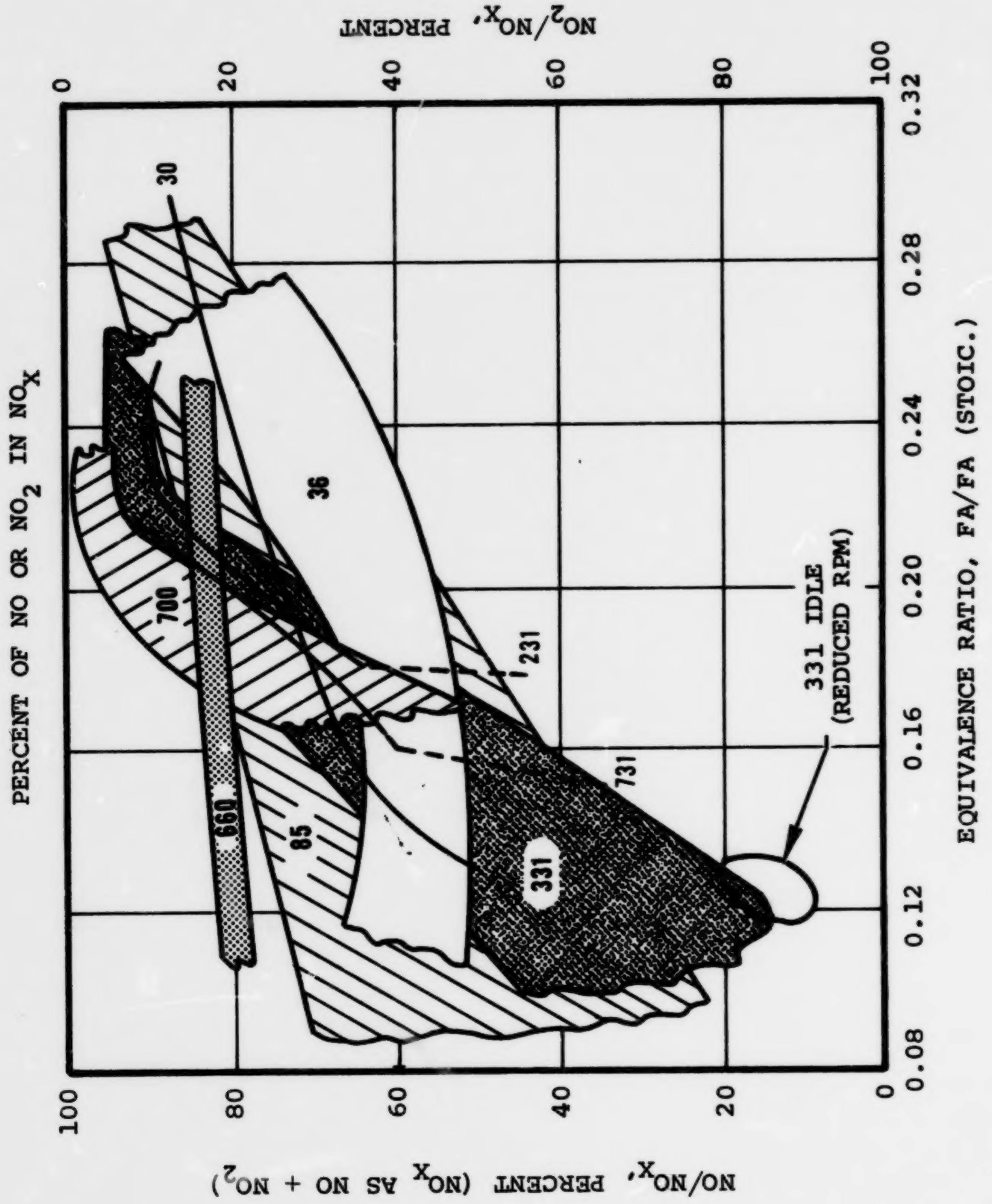
PERCENT OF NO OR NO_2 IN NO_X
NO_2/NO_X, PERCENT
0
20
40
60
80
100
NO/NO_X, PERCENT (NO_X AS NO + NO_2)
100
80
60
40
20
0
EQUIVALENCE RATIO, FA/FA (STOIC.)
0.08
0.12
0.16
0.20
0.24
0.28
0.32
30
36
700
660
85
331
231
731
331 IDLE
(REDUCED RPM)

FIGURE 4

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TABLE 1

ENGINE EXHAUST EMISSIONS OVER COMPLETE OPERATING LOAD RANGE

Engine Model Series		731	231	331	30	36	85	660	700
No. of Engines Tested		1	1	4	1	2	18	2	2
Emission Measured		Measured Max/Min Emission Concentrations in PPM(1)							
CO_2	max	3.03	3.59	3.64	4.07	3.80	4.0	3.45	3.18
	min	2.03	2.46	1.44	1.72	1.52	1.22	1.58	2.28
CO	max	464.0	345.0	482.0	331.0	292.0	502.0(4)	197.0	251.0
	min	24.7	61.4	13.6	107.0	100.	90.0	77.1	14.8
HC (HOT) (as methane)	max	253.0	99.0	1037.0	52.6	14.6	222.0	28.5	160.0
	min	0.8	7.6	1.3	3.2	0.3	0.3	8.4	18.1
NO	max	110.0	123.0	120.0	41.8	54.7	62.0	56.8	109.0
	min	6.2	16.8	1.9	7.7	11.3	1.2	17.0	20.8
NO_x (as NO_2)	max	116.0	135.0	126.0	45.9	61.5	71.2	67.8	114.0
	min	13.9	31.2	11.0	12.7	18.1	7.7	20.8	33.4

NOTES:

(1) Emissions data expressed as PPM defined as the volumetric concentration of pollutant in total wet exhaust products; except CO_2 is expressed as mole. percent by volume.

(2) Emissions data measured under Phoenix altitude, ambient temperature and pressure conditions.

(3) This table does not include GTCP30-92 engine (fuel vaporizer combustion system) test results.

(4) The maximum CO concentration for the 85 Series engine excluding the GTCP85-90/90B (ground cart application) was 355 ppm.

The 731, 231, and 85 Series engines produced the highest CO emissions with a maximum level of 500 ppm from an 85 Series engine. The 331 Series engines produced the highest hydrocarbon emissions with the maximum value of 1037 ppm on ground idle, and the 731, 231, 331, and 700 Series engines produced highest NO-NO_x emissions. The emissions levels of Table 1 are not necessarily representative of the relative emissions standing of each series when the engines are operated over their "weighted" duty cycles as discussed and shown in Section 5. Table 13 shows that when operated under an estimated duty cycle the 660 Series engine produces the most CO_2, CO, and NO_x emissions and the 700 Series produces the most unburned hydrocarbons in the auxiliary power unit groups. This is because their duty cycle time is greater than other engines and in some cases their emission formation rates are higher than other auxiliary power units. On the basis of total average weight of emissions per year, Table 13 shows that the 85 Series engines are the largest contributors because of the large quantity of engines operating in the field. It was determined that the 731, 231, and 331 Series engines lose their significance as large emitters on a duty cycle or total annual emissions comparison basis. Table 16 shows these values for the turboprop 331 Series engines.

Table 2 gives a relative comparison of the engines series tested at idle and maximum load operation. This table essentially defines the emissions envelope maximum and minimum test values for all product lines tested at a minimum load condition (flight idle or 100 percent speed) and a maximum load condition (maximum exhaust gas temperature). Under low loadings (low equivalence ratios) or high loadings (high equivalence ratios) the 85 Series engine generated the highest CO and HC emissions, and the 731, 231 331, and 700 Series engines created the highest NO-NO_x emissions. Lowest emissions of CO and HC occur at maximum load and for NO-NO_x at idle.

TABLE 2

MEASURED MAX/MIN POLLUTANT CONCENTRATIONS WITH RESPECT TO POWER SETTING

ENGINE MODEL SERIES

RANGE OF MEASURED EMISSION CONCENTRATION, PPM(1)

Emission		731	231	331	30	36	85	660	700
No. Engines Tested		1	1	4	1	2	18	2	2
Idle Condition									
CO_2	max	2.20	2.50	1.86	1.72	1.63	1.49	1.63	--
	min	2.20	2.50	1.44	1.72	1.52	1.22	1.58	2.32
CO	max	264.0	161.0	248.0	331.0	146.0	420.0	116.0	78.7
	min	264.0	161.0	125.0	331.0	114.0	125.0	77.1	--
HC (Hot)	max	84.7	21.5	138.0	52.6	14.2	222.0	21.3	58.4
(as methane)	min	84.7	21.5	24.5	52.6	3.5	4.0	11.2	--
NO	max	14.5	31.0	21.3	7.7	16.0	12.0	18.4	52.6
	min	14.5	31.0	6.1	7.7	11.3	1.2	17.0	--
NO_x	max	21.1	42.5	42.0	12.7	21.3	21.4	23.5	64.3
(as NO_2)	min	21.1	42.5	20.0	12.7	18.1	7.7	20.8	--
Full Load									
CO_2	max	3.03	3.59	3.64	4.0	3.80	3.94	3.32	3.10
	min	3.03	3.59	3.40	4.0	3.79	3.16	3.30	3.06
CO	max	24.7	61.4	38.9	112.0	243.0	298.0	177.0	22.1
	min	24.7	61.4	13.6	112.0	117.0	109.0	143.0	20.4
HC (Hot)	max	0.8	7.6	5.9	3.8	3.9	73.3	15.0	69.6
(as methane)	min	0.8	7.6	1.3	3.8	0.4	1.1	10.0	28.8
NO	max	110.0	123.0	120.0	39.2	47.5	60.1	53.9	90.8
	min	110.0	123.0	62.0	39.2	47.4	30.2	46.5	76.1
NO_x	max	116.0	135.0	126.0	42.7	59.7	66.4	64.8	94.3
(as NO_2)	min	116.0	135.0	66.5	42.7	54.7	38.8	55.0	79.7

NOTES:

1. Emission concentration measured in parts per million, ppm, by volume except CO_2 as mole percent.
2. Idle operation given for propulsion engines is flight idle condition or power setting 2. For APUs idle represents 100 percent speed power setting 1 except for the 700-4 idle represents 91 percent speed "standby mode" of power setting 2.
3. Full load operation for propulsion engines is represented by power setting 20 and for combination load APUs as power setting 15.
4. Power setting numbers represent reference engine load conditions as defined in Table 6.
5. These data summarize the measured emissions performance data reduction printout enclosed as Appendix B of this report.

All engines produced higher levels of NO_2 emissions than were suspected to exist in either gas turbine exhaust emissions as reported in other industry surveys or from chemical kinetics formation reactions. Figure 4 shows the highest NO_2 levels occurring at idle with NO_2 comprising one-fourth to three-fourths of the total oxides of nitrogen generated. A check of several data points using a non-dispersive ultra-violet (NDUV) analyzer was made to confirm the magnitude of NO_2 readings on the chemiluminescent analyzer. The effect of water vapor in the exhaust gas on the reading level of the chemiluminescent analyzer was also checked by an ice bath condenser, described in Section 5., and found to agree closely with calculated values. It is important to realize that the total oxides of nitrogen as $NO + NO_2$ emitted from gas turbines appears considerably higher if expressed as NO_2 rather than $NO + NO_2$. The effect of an expression using the NO_2 molecular weight is shown by Figure 21 to be about 50 percent greater than the actual emission of $NO + NO_2$ from the TFE731-2. This practice as requested by the Office of Air Programs intends to allow for the photoreactivity of NO in the atmosphere with conversion to NO_2 in 3 to 5 hours.

The statistical approach to catagorizing engine families is shown in Tables 14 and 17. Statistical definition of upper emissions levels that would include a high proportion of an existing gas turbine population is not considered practical. This is because emissions levels of identically designed production gas turbines vary by such large amounts that a statistical upper control limit to include a high percentage of an existing population becomes unreasonably high.

Three sampling probe measuring techniques were used to obtain gas samples during this program. The single point fixed probe is the easiest to use but cannot be accepted as reliable due to significant radial and circumferential emissions stratification as discussed in Section 5. The 12 point fixed probe is next easiest to use but when compared to a single point movable probe small differences in readings resulted as shown in Table 7, Section 5. Additional sampling should be conducted with this probe on engines with large exhaust emissions stratifications to substantiate the validity of its averaging ability. The single point movable probe is considered the most accurate measuring method and was used on all engines measured in this program.

Although smoke measurements were not taken in this report, the single point movable probe was designed and used according to SAE Recommended Practice ARP-1179. A trend to include smoke measurements in emissions tests would suggest that emissions measurement procedures adopt the probing technique of ARP-1179 or a change be made to the smoke measuring practice to reflect the emissions measuring probing technique preferred.

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3. DESCRIPTION OF TEST ENGINES

The emissions measurement test program conducted at AiResearch Manufacturing Company of Arizona under the Environmental Protection Agency involved tests on a total of 32 auxiliary power and prime propulsion gas turbine engines designed for business/executive aircraft and military and commercial airline transport aircraft. Table 3 shows a list of the gas turbine engine models tested, present application, and the maximum rated performance for the application shown. Basically 15 different engine models comprise the 32 gas turbines tested.

The basic number shown denotes a given engine model series all members of which have basically the same power section configuration. The dash number reflects a particular engine model different from the other engines in the same series by combinations of the performance rating definition, a growth version, application, or change in external configuration required for a given installation. Finally, the preceding letter code describes the gas turbine's basic function. For example, GTCP means a gas turbine compressor unit with shaft power capabilities and TSCP means twin-spool compressor and shaft power unit, while TPE, TSE, and TFE denotes turboprop, turboshaft, and turbofan engines respectively.

The functions of an auxiliary power unit (APU) are to provide combinations of shaft power (for generators and other accessories) and bleed-air for aircraft engine starting, aircraft air conditioning, anti-ice, and heating systems.

The 36, 85, 660, and 331 Series gas turbines are single-shaft engines that operate at essentially constant speed over the range of load conditions. The 700 and 731 Series are twin-spool engines that operate at variable low pressure spool speeds. Of particular significance from the standpoint of the emission study are the variation in cycle characteristics and the difference in the combustion systems

TABLE 3

APPLICATION DATA SUMMARY OF AIRCRAFT AUXILIARY POWER AND PROPULSION UNITS

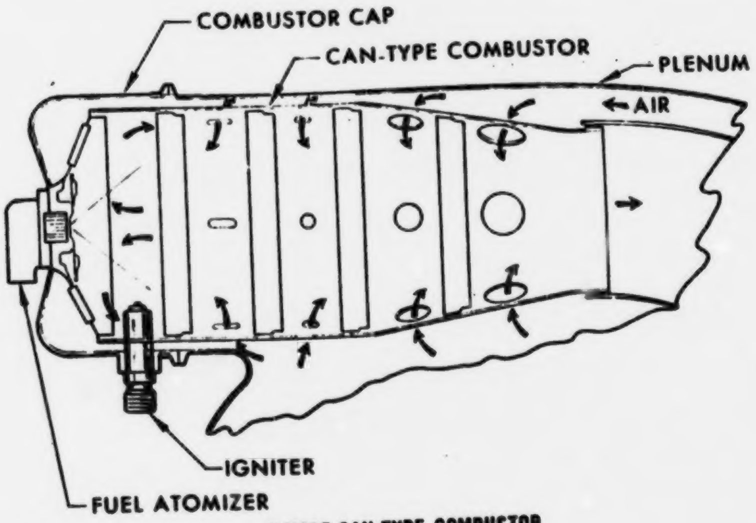
				MAXIMUM RATED PERFORMANCE* (SEA LEVEL, STATIC, U.S. STANDARD DAY EXCEPT AS NOTED)		
Engine Model	Application	Number Engines Tested	Engines Delivered Thru May '71	Shaft Load shp	Bleed Air Extraction lb/min	Inlet Temp Other Than 59°F
Small APUs						
GTCP30-92	Executive Jets	2	230	40	28.5	113
GTCP36-6	Grumman Gulfstream II	2	140	30	53	
Commercial Aircraft APUs						
GTCP85-98	Boeing 727-100	3	720	100	108	100
GTCP85-98CK	Boeing 272-100, -200	6	325	100	128	100
GTCP85-180 (98CK)	Military (substitute for 98CK)		325	177	158	
GTCP85-98D	McDonnell-Douglas DC-9	2	790	94	67	103
GTCP85-115	BAC 1-11/400, 500	3	325	40	110	100
GTCP85-129	Boeing 737	1	335	200	110	100
GTC85-90/90B	Air Ground Cart	3	940	0	124	
GTCP660-4	Boeing 747	2	225	63	493	
TSCP700-4	McDonnell-Douglas DC-10	2	15	142	385	103
Propulsion Engines						
TPE331-201A/151G	Skyvan, CASA (212)	2	321	715,665		
TPE331-3U-303G	Swearingen (Merlin IIC)	0	60	840		
TPE331-43A	Aero Commander (NAR)	1	86	575		
T76-G-410	Military (substitute for 201A)	1	820	720		
TSE231-1	Development Unit for Lear (Gates) and Bell Helicopter	1	0	474		
				THRUST, LB		
TFE731-2	Development Unit for Dassault Falcon 10, Lear Jet 26, and Swearingen SA28T	1	2	3500		
	Total	32				

* Performance Ratings Shown are less than or equal to Engine Power Settings used in the Emissions Measurement Test Program. Maximum loads shown may not be simultaneously possible in all cases.

Total Military and Commercial Auxiliary Power Units Delivered Through May 1971 = 21,745 Approx.
Total Military and Commercial Aircraft Propulsion Engines Delivered Through May 1971 = 2,329 Approx.

of the basic engine series. The three basic types of combustion systems used in the gas turbine for this emission study are shown in Figure 5.

A basic description of each engine series tested plus a cross-section view of each are included in the following engine series information cards provided by the AiResearch Sales Department.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CAN-TYPE COMBUSTOR
PLENUM
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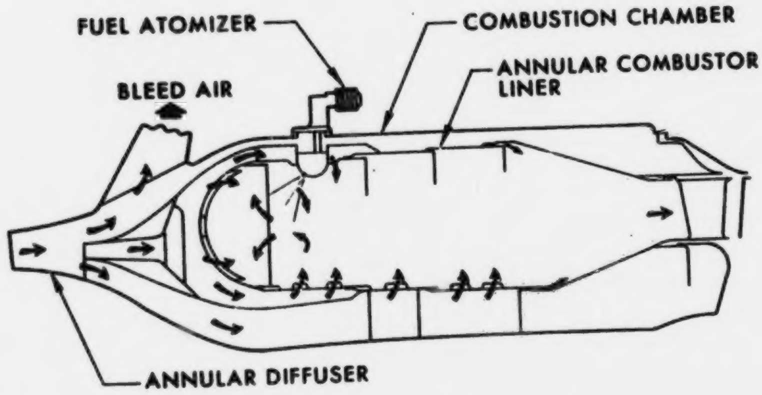
SINGLE-CAN-TYPE COMBUSTOR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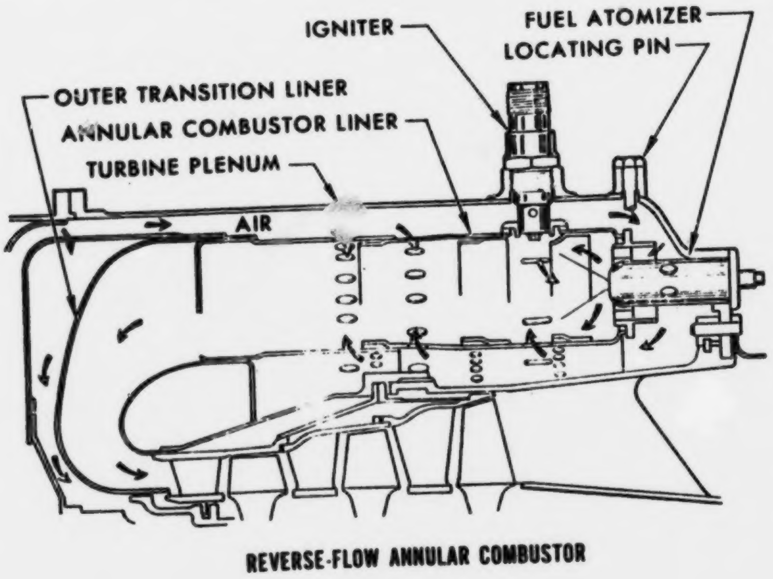
BLEED AIR
ANNULAR DIFFUSER

STRAIGHT-THROUGH ANNULAR COMBUSTOR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FUEL ATOMIZER
LOCATING PIN
OUTER TRANSITION LINER
ANNULAR COMBUSTOR LINER
TURBINE PLENUM
AIR

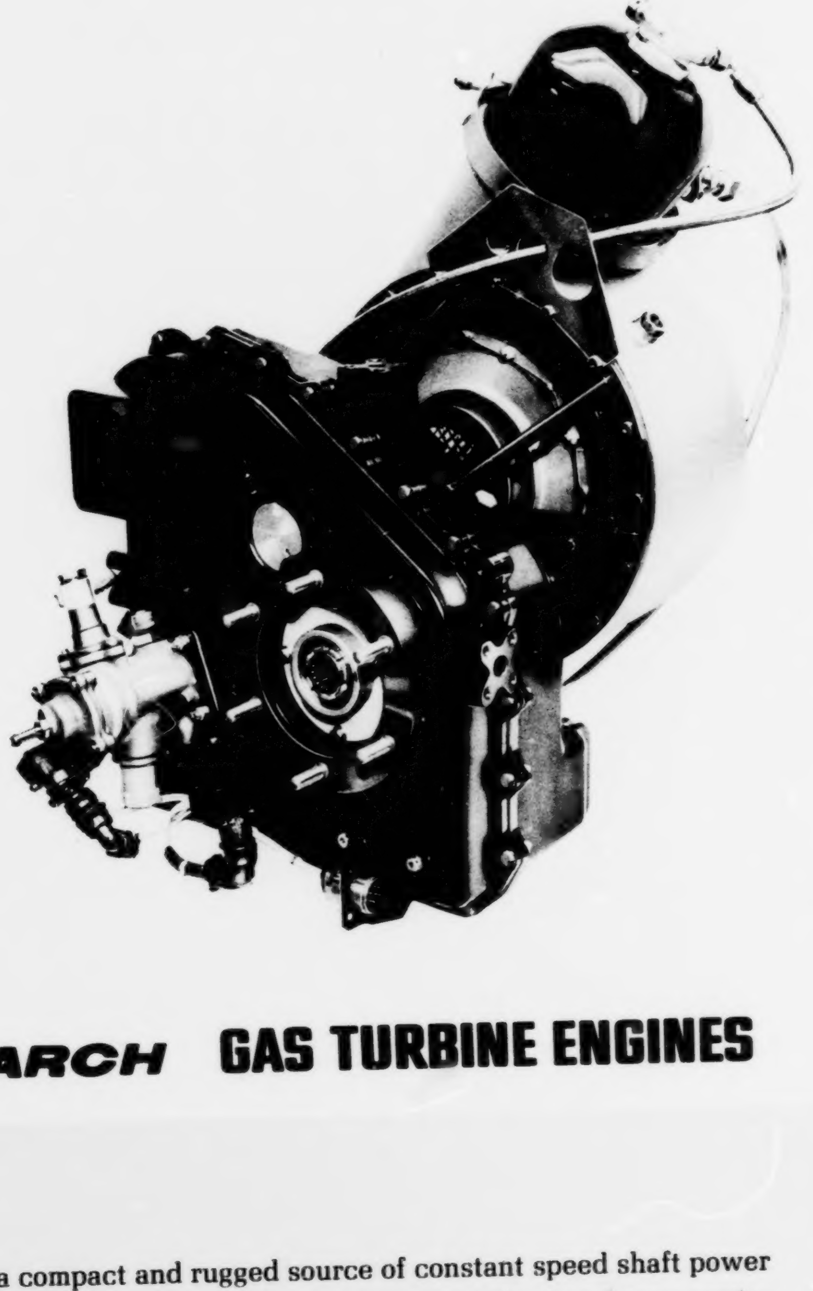
REVERSE-FLOW ANNULAR COMBUSTOR

TYPICAL COMBUSTION SYSTEMS USED IN AIRESEARCH ENGINES

FIGURE 5

SERIES 30

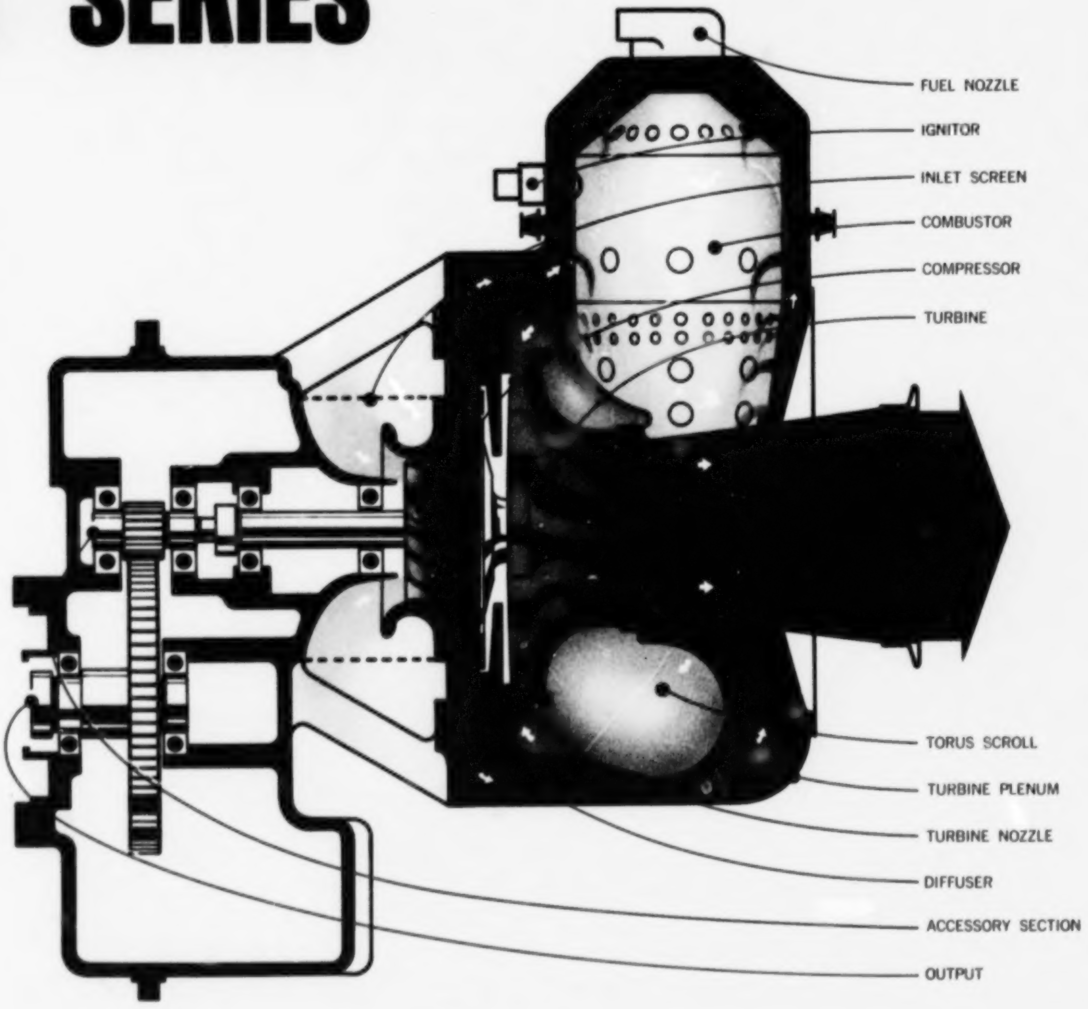
The "30" series Gas Turbine is the smallest of the AiResearch engines. Various models of this engine produce shaft power in a range from 60 to 150 H.P. and weigh approximately 75 pounds.



AIRESEARCH GAS TURBINE ENGINES

The "30" engine is a compact and rugged source of constant speed shaft power for driving generators, alternators, pumps, compressors and other driven equipment. Most installations require only shaft horsepower, however, some models of this engine can provide a continuous supply of bleed air in combination with shaft power. Some typical applications of the "30" are: business aircraft auxiliary power units, generator sets for ground power and pump drives.

30 SERIES



The "30" series Gas Turbine Engine is the simple, open-cycle coupled-turbine type, consisting of compressor, combustor, turbine assembly, output shaft and accessory drive. In addition, the unit incorporates fuel, lubrication, and control systems. All components are assembled into a single unit.

The compressor is a single-stage centrifugal type utilizing an open-faced, backward-curved impeller. Air flows through a screen inlet, is compressed in the impeller and diffused in a radial, vaned diffuser, discharging into the outer plenum surrounding the nozzle and turbine torus assembly. The impeller is mounted on a common shaft with the turbine rotating assembly and the accessory assembly. The shaft is supported by two high-speed bearings.

The power turbine section consists of a turbine assembly, a plenum and a torus, and a combustor chamber assembly. The plenum serves as a receiver for the compressor discharge air and as an enclosure for the combustion flame tube and the torus. The torus, mating with the discharge end of the combustor chamber flame tube, directs the hot combustion gases through a fixed area nozzle ring against the turbine wheel.

The accessory section with integral drive pad and output shaft includes the following: an oil pump assembly including pressure pump, oil filter, by-pass and relief valves; a fuel accessory assembly which includes fuel pump, fuel filter, relief and by-pass valves, governor and fuel shutoff valve. Unit speed is regulated by a governor in the fuel pump and control unit assembly.

The engine contains controls suitable for completely automatic starting. These controls properly sequence starter operation, fuel control, and ignition to provide a stable automatic starting cycle requiring only the engagement of a single starter switch. Additional controls provide continuous operating adjustments to compensate for variations in shaft power requirements, and ambient conditions.

For detail information on the specific gas turbine engine for your requirements call your nearest Garrett Corporation Office, or send your problem statement directly to:

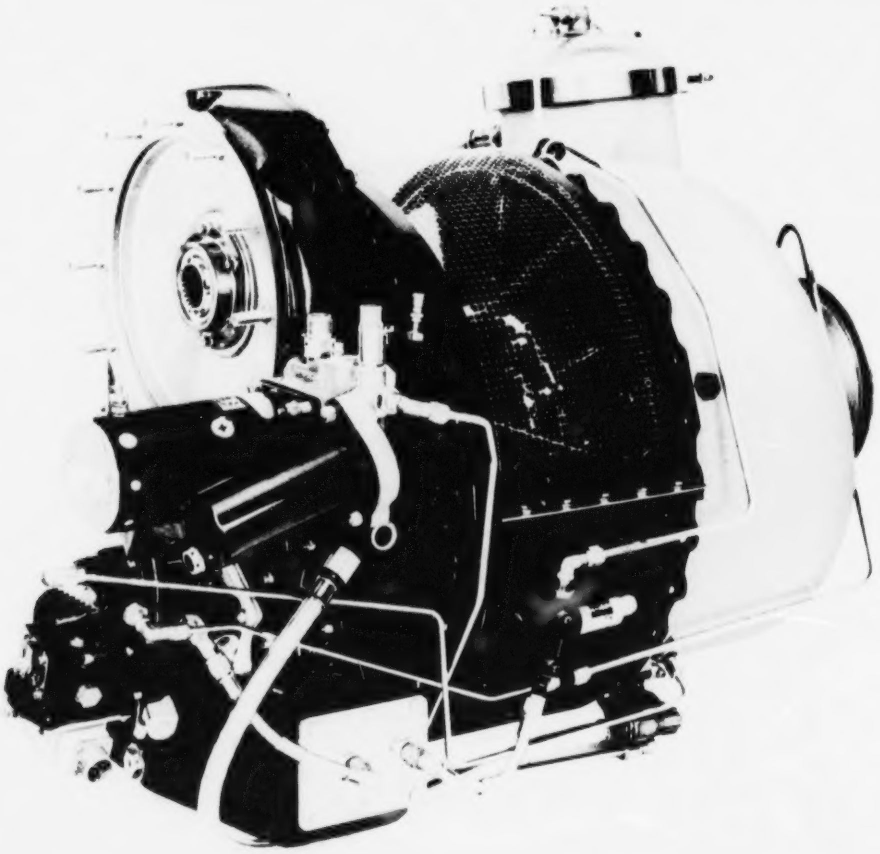
GARRETT

GAS TURBINE SALES
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA, 402 South 36th Street, Phoenix, Arizona 85034

SERIES 36

The "36" series gas turbine is one of the latest designs to join the AiResearch family of engines.

It will supply about 70 pounds of bleed air per minute, approximately 200 shaft horsepower, or, varying combinations of both at the same time. This engine weighs approximately 140 pounds.

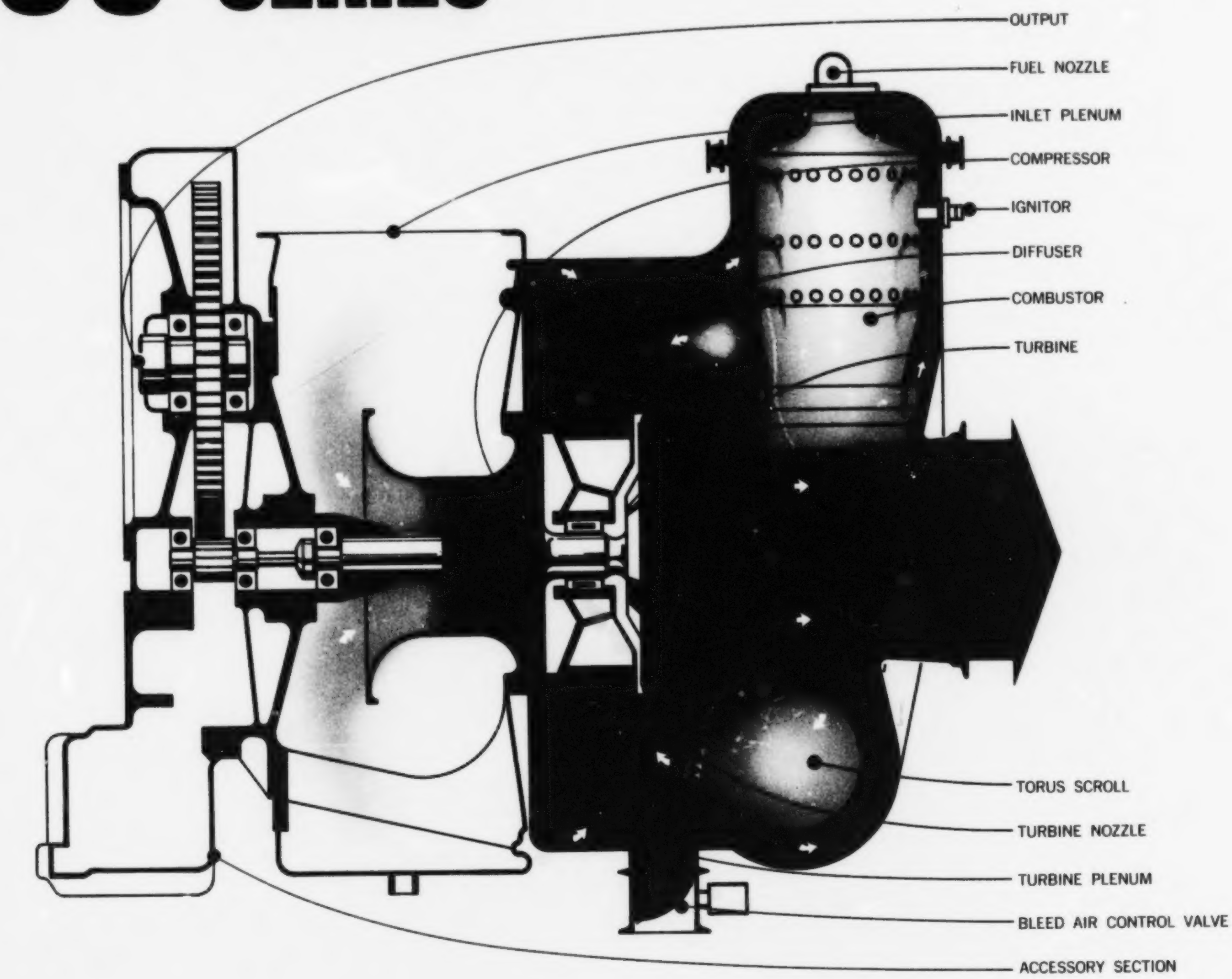


AIRESEARCH GAS TURBINE ENGINES

The "36" series gas turbine is a compact and rugged source of pressurized and heated air in addition to shaft power. The pneumatic energy is used in a variety of applications for jet engine starting systems, air conditioning systems, anti-ice and heating systems. The shaft power output is used for driving generators, alternators, pumps, compressors and other driven equipment. Typical applications of the "36" are: ground power utility packages providing electrical power and air conditioning services, airborne auxiliary power units and generator sets.

MS 1404-2

36 SERIES



The major components of the "36" series Gas Turbine Compressor and Power Unit include a single-stage single-entry centrifugal compressor, a single can-type combustor, a single-stage radial-inflow turbine, accessory section with an integral output pad, and the controls and accessories necessary for automatic starting and governed-speed operation of the engine. The compressor and turbine rotating elements are mounted on a single shaft supported by two bearings.

Air enters the inlet screen and plenum and is compressed by the backward-curved centrifugal impeller and radial diffuser system. The compressed air is discharged into the annular plenum where a controlled portion of it can be bled off for external use. The remaining air is directed into the reverse-flow single-can combustor. Fuel is added through a single nozzle and the temperature of the burned mixture is raised to the value required for the particular engine load. From the combustor, the hot gas is directed by the scroll and fixed-area nozzle through the turbine wheel to produce the power required for driving the compressor, accessories, and the output load.

The accessory section provides drives for the oil pressure pump, oil scavenge pump, fuel control and starter motor in addition to the output pad for the generator or other major driven equipment.

The "36" series engine includes controls for completely automatic starting and operation. They sequence starter operation, fuel control and ignition to provide a stable starting cycle requiring only the engagement of a single starter switch. They also provide continuous control to compensate for variations in power requirements and ambient conditions.

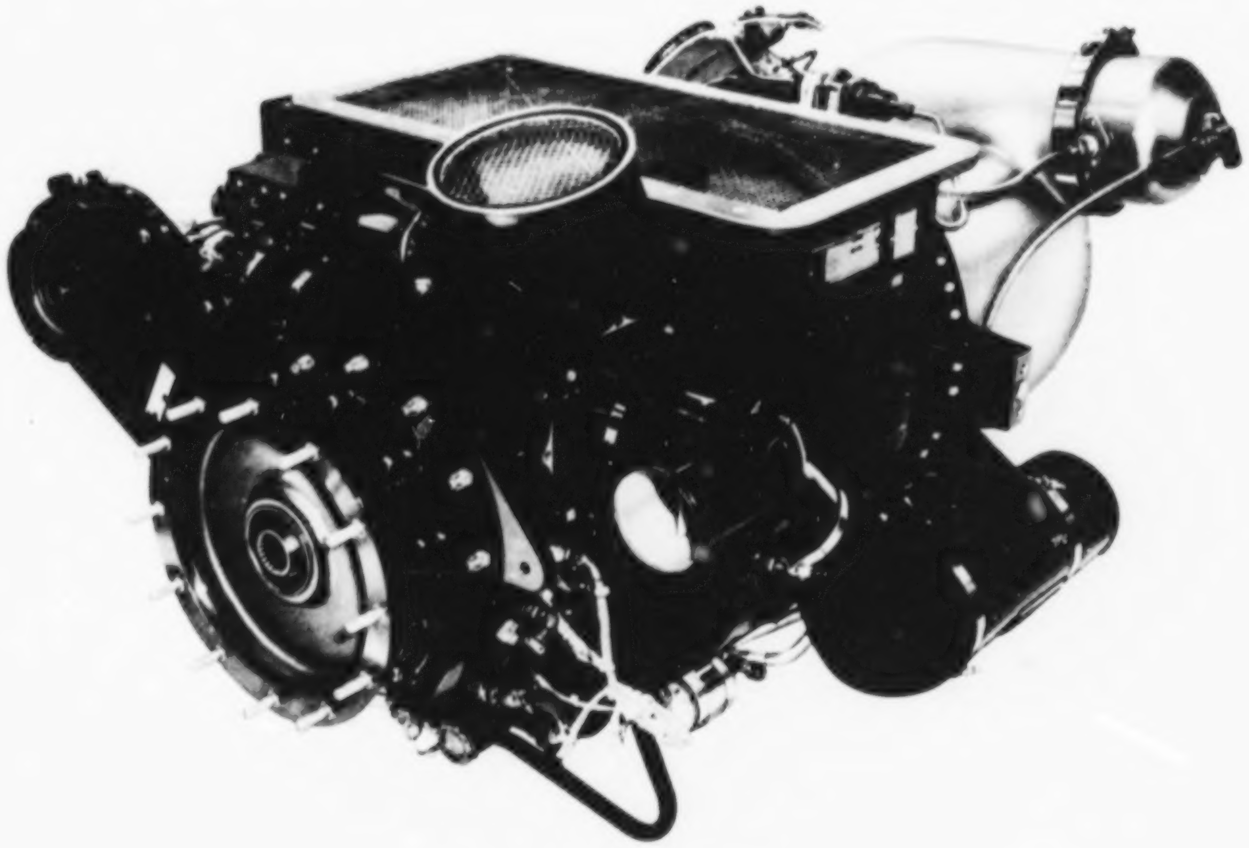
For detail information on the specific gas turbine engine for your requirements call your nearest Garrett Corporation Office, or send your problem statement directly to:

GARRETT

GAS TURBINE SALES
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA, 402 South 36th Street, Phoenix, Arizona 85034

SERIES 85

The "85" Series Gas Turbine has the largest production history and variety of applications of the AiResearch engines. Models of this engine develop power in the 200 to 350 equivalent H.P. range and weigh approximately 275 pounds. Most applications utilize this power in a combination of varying amounts of shaft power and compressed air energy.

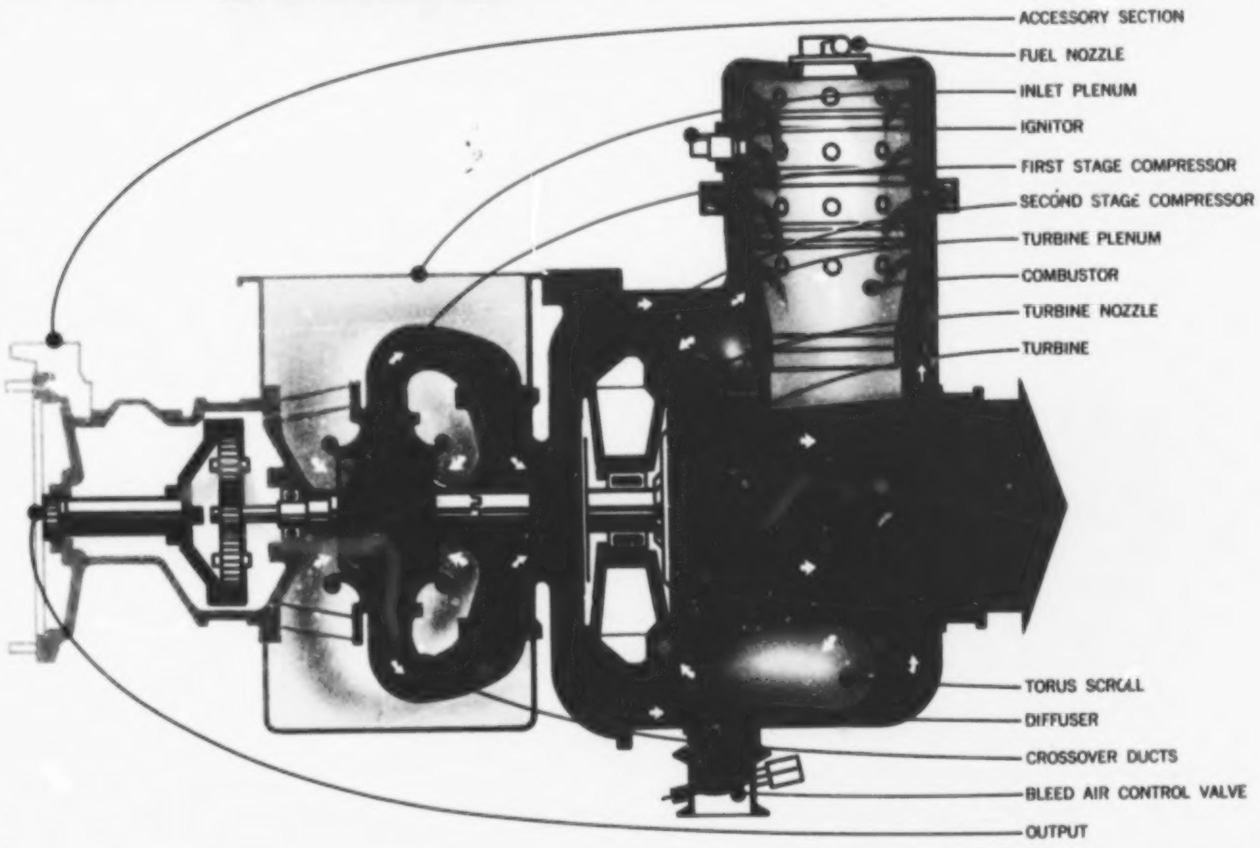


AIRESEARCH GAS TURBINE ENGINES

The "85" engine is a compact and rugged source of pressurized and heated air. This pneumatic energy is used in a variety of applications for jet engine starting systems, air conditioning systems, anti-ice and heating systems. A few installations require only this pneumatic power but many models of the "85" also provide shaft power at the same time. This shaft power is used for driving generators, alternators, pumps, compressors and other driven equipment. Typical applications of the "85" are: airline and military transport aircraft auxiliary power units and generator sets for ground power.

MS 1404-4

85 SERIES



The basic "85" series gas turbine includes a compressor, turbine, and an accessory section with controls.

The compressor section is designed to provide a source of compressed air for the turbine and for external pneumatic power. The compressor is a two-stage centrifugal type utilizing two radial outward flow impellers. Air enters the double entry first stage impeller through a compressor inlet plenum, flows through a vaned diffuser into crossover ducts leading into the inlet of the single entry second stage. Air discharges from the second stage compressor through a vaned diffuser into the turbine plenum.

The turbine section consists of a turbine assembly, pneumatic bleed port and control, plenum and torus, and a combustor chamber assembly. The plenum serves as a receiver for the compressor discharge air and as an enclosure for the combustion chamber and the torus. The torus, mating with the discharge end of the combustor chamber flame tube, directs the hot combustion gasses through a fixed-area nozzle ring against the turbine wheel. The main rotating assembly is mounted on pressure lubricated bearings.

The accessory section includes: An oil pump assembly including pressure pump and dual scavenge pump, oil filter, by-pass valve, and relief valve; a fuel accessory assembly which includes fuel pump, fuel filter, relief and by-pass valves, governor, and fuel shutoff solenoid; a centrifugal three-speed switch, starter motor and a cooling fan. Fan air capacity is sufficient for cooling lubricating oil, and for cooling driven equipment. The lubricating oil is passed through an oil-to-air heat exchanger which is mounted on the unit. Action of the fuel governing system depends upon a functional relationship between load and governed speed for adequate stability. The accessory section includes an integral drive pad and output shaft where shaft horsepower is required in combination with bleed air power.

The "85" is equipped with a fully automatic control system which properly sequences starter operation, fuel control, and ignition to provide a stable automatic starting cycle requiring only the engagement of a single starter switch. Additional automatic controls provide continuous operating adjustments to compensate for variations in compressor bleed load, shaft power requirements and ambient conditions.

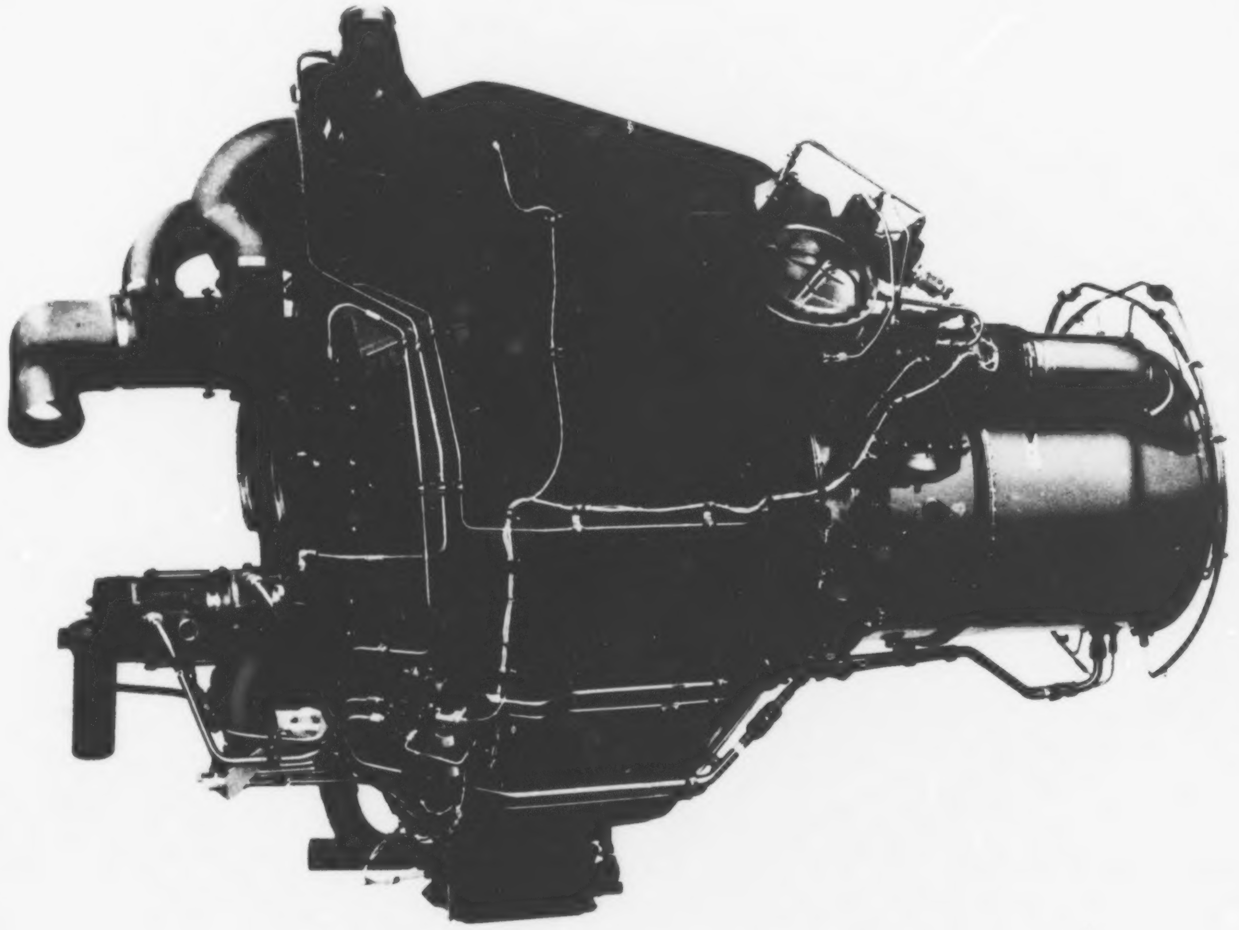
For detail information on the specific gas turbine engine for your requirements call your nearest Garrett Corporation Office, or send your problem statement directly to:

GARRETT

GAS TURBINE SALES
AIRESEARCH MANUFACTURING COMPANY OF ARIZONA, 402 South 36th Street, Phoenix, Arizona 85034

SERIES 660

The "660" series gas turbine is the largest engine of its kind available. Approximately 300 shaft horsepower, 700 pounds per minute bleed air, or varying combinations of both at the same time are available from this 560 pound engine.

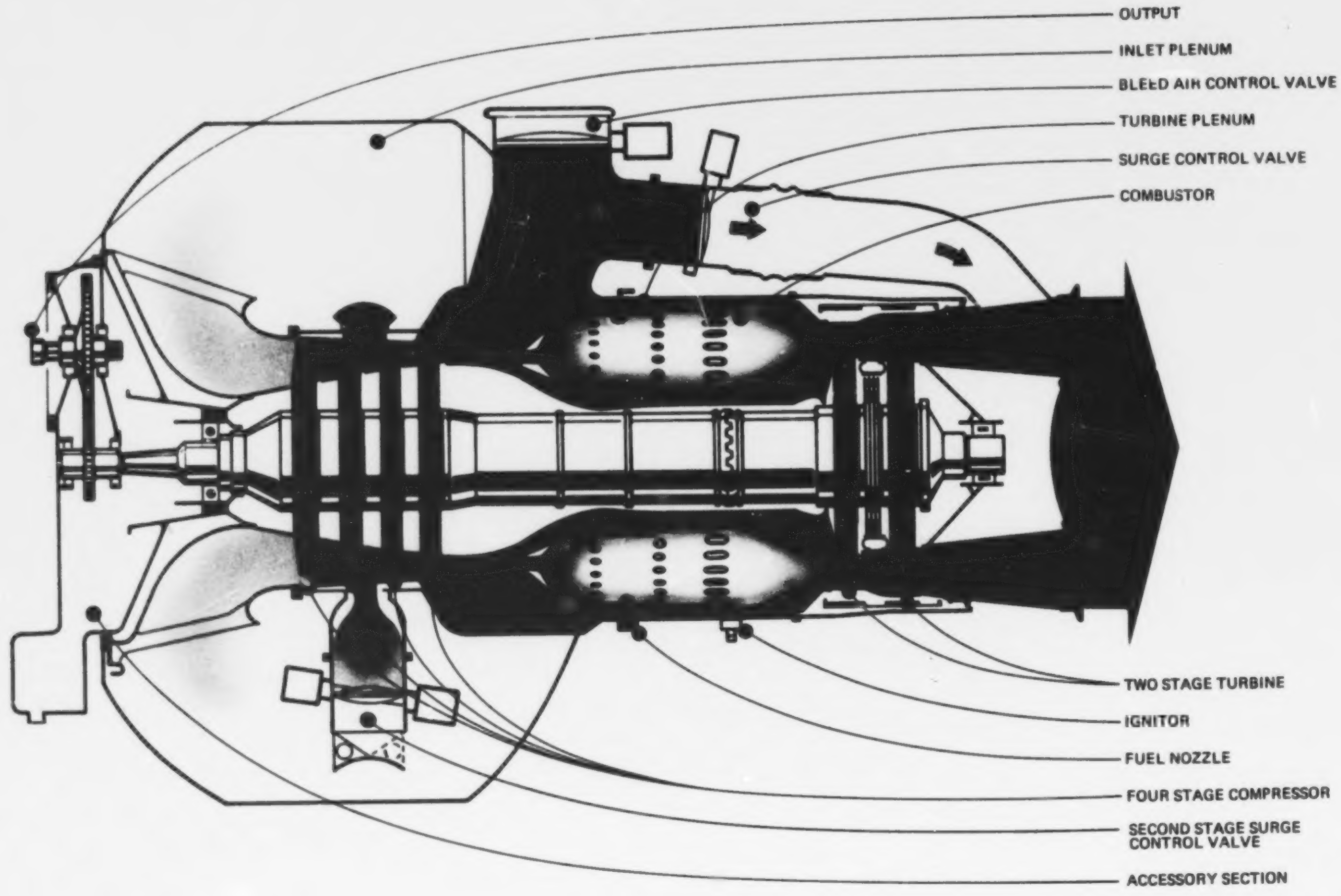


AIRESEARCH GAS TURBINE ENGINES

The "660" engine is one of the latest developments in large airborne auxiliary power units. This rugged engine produces very large quantities of heated and pressurized air to be used in aircraft engine starting systems, air-conditioning systems, anti-ice and heating systems. The "660" also provides the shaft power required for driving generators, alternators, pumps, compressors and other driven equipment. Experience gained from the world leadership of AiResearch in development, production and support of gas turbine engines guarantees the future of the "660" as an efficient and dependable engine. New models of these engines will be able to take full advantage of the growth capability of the basic design. Typical applications of the "660" are: large transport aircraft onboard auxiliary power units and as ground power equipment.

MS 1409-11

660 SERIES


OUTPUT
INLET PLENUM
BLEED AIR CONTROL VALVE
TURBINE PLENUM
SURGE CONTROL VALVE
COMBUSTOR
TWO STAGE TURBINE
IGNITOR
FUEL NOZZLE
FOUR STAGE COMPRESSOR
SECOND STAGE SURGE CONTROL VALVE
ACCESSORY SECTION

The basic "660" series gas turbine includes a compressor, turbine and accessory section with controls.

The compressor section is designed to provide the compressed air required for engine operation, as well as the large quantity that is taken as pneumatic power for external use. Air from the inlet plenum enters the four-stage axial compressor. The compressed air is then diffused to a lower velocity as it is directed into the turbine plenum where a controlled quantity can be bled for external use. The rest of the compressed air enters the annular combustor where fuel is added and the temperature of the burned mixture is raised to the value necessary to meet load requirements. The hot gas from the combustor is then directed through the first and second stage axial turbines where the power is extracted to drive the compressor, accessories and shaft power output. The main rotating shaft is mounted on two bearings.

The accessory section includes an integral output pad for driven equipment as well as the necessary electrical fuel and oil system components. These include an oil cooler that is mounted on the engine. The "660" is equipped with a fully automatic control system that properly sequences starter operation, fuel control, ignition, and surge control to provide a stable automatic starting cycle requiring only the engagement of a single starter switch.

Additional automatic controls provide continuous operating adjustments to compensate for variations in bleed air load, shaft power requirements and ambient conditions.

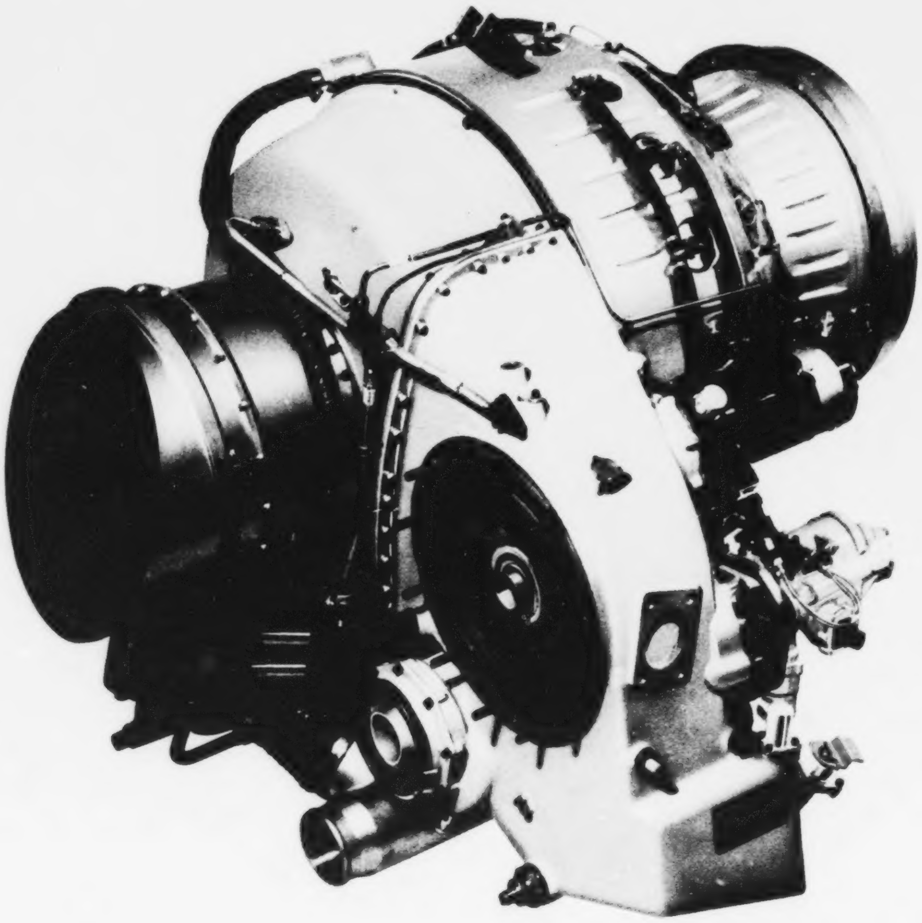
For detail information on the specific gas turbine engine for your requirements call your nearest Garrett Corporation Office, or send your problem statement directly to:

GARRETT

GAS TURBINE SALES
AIRESEARCH MANUFACTURING DIVISION OF ARIZONA, 402 South 36th Street, Phoenix, Arizona 85034

SERIES 700

The "700" series gas turbine is a Twin-Spool Compressor and Power engine (TSCP) that weighs approximately 550 pounds. It provides over 150 shaft horsepower along with approximately 350 lbs/min of compressed air energy and has been designed for easy maintenance and long life.



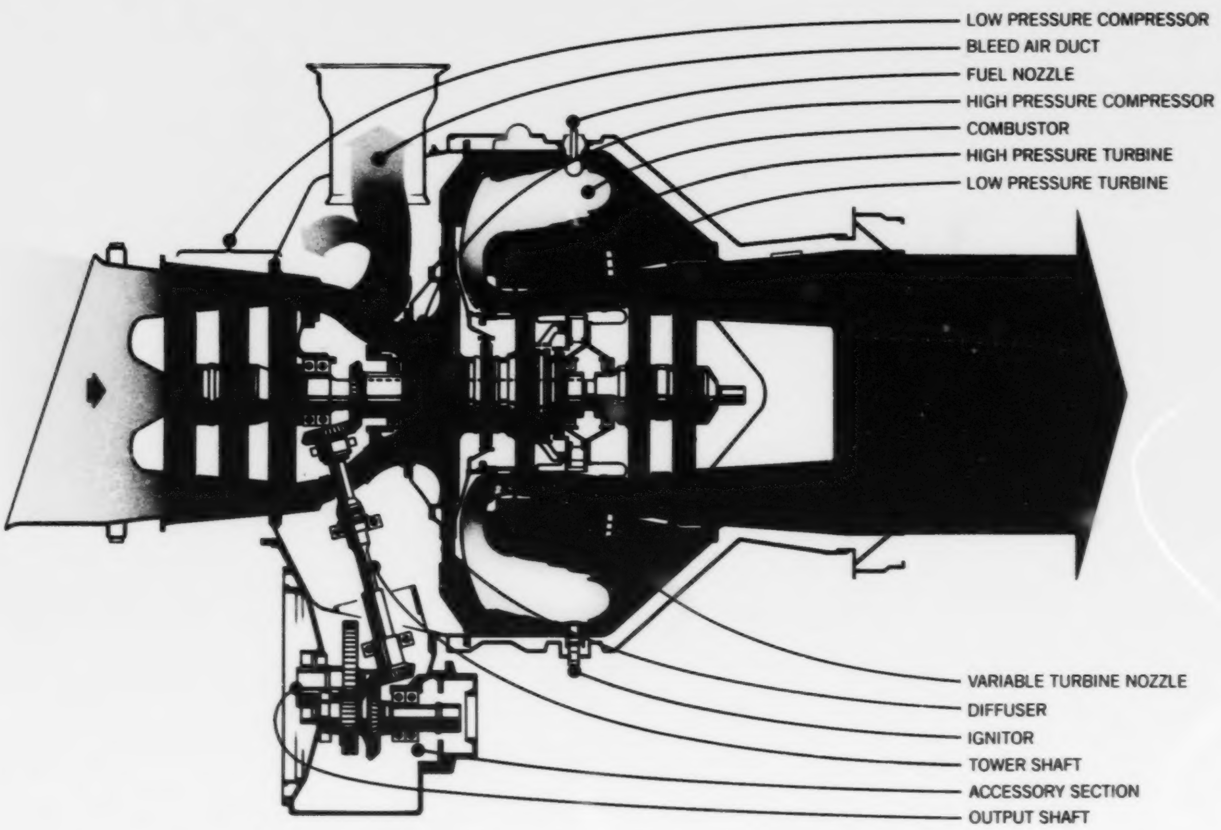
AIRESEARCH GAS TURBINE ENGINES

The series "700" gas turbine is an advanced-technology engine that provides the most favorable fuel consumption characteristics possible with the current state of the art, coupled with the excellent maintainability required for airline APU operation. This optimized cycle is accomplished with a twin-spool, coaxial, high-pressure-ratio cycle with shaft power extraction from the constant speed high-pressure spool and bleed air from the low-pressure spool. Variable nozzles are provided at the first-stage turbine of the low-pressure spool to control the pneumatic output to satisfy the load requirements and thus minimize the fuel consumption.

Typical applications of the "700" include the new large commercial transport aircraft where this advanced APU furnishes the pneumatic power for air-conditioning systems, main engine starting, and the shaft power for the auxiliary electrical and hydraulic systems.

MS 1409-12

700 SERIES


LOW PRESSURE COMPRESSOR
BLEED AIR DUCT
FUEL NOZZLE
HIGH PRESSURE COMPRESSOR
COMBUSTOR
HIGH PRESSURE TURBINE
LOW PRESSURE TURBINE
VARIABLE TURBINE NOZZLE
DIFFUSER
IGNITOR
TOWER SHAFT
ACCESSORY SECTION
OUTPUT SHAFT

The "700" series gas turbine is a two-spool engine with the high-pressure spool operating at a constant speed and the low-pressure spool operating over a controlled speed range.

The high-pressure spool has a single stage radial compressor driven by a single stage axial flow turbine. The output power of the high-pressure spool is transmitted to the gearbox to provide constant speed shaft power for the engine accessories and the customer furnished driven equipment.

The three-stage, axial-flow, compressor of the low-pressure spool is driven by a two-stage axial-flow turbine. Bleed air is extracted from the engine through ports located between the last stage of the low-pressure compressor and the inlet to the high-pressure compressor. The variable flow feature of the low-pressure turbine nozzle permits control of the energy delivered to that turbine and the resulting speed control of the low-pressure spool that limits bleed air output to the level required to satisfy the selected operating conditions.

Air from the inlet duct is compressed by the low-pressure compressor and flows to the inlet of the high-pressure compressor. The output of the high-pressure compressor is diffused and directed through the annular combustor where it picks up the heat energy from the burning fuel/air mixture. The high-energy gases are directed through the high-pressure turbine and finally through the two-stage turbine of the low-pressure spool.

The "700" series engine is equipped with a fully automatic control system that sequences starter, fuel control, ignition and all other functions to assure a stable automatic starting cycle as well as maintaining control over all operating conditions.

For detail information on the specific gas turbine engine for your requirements call your nearest Garrett Corporation Office, or send your problem statement directly to:

GARRETT

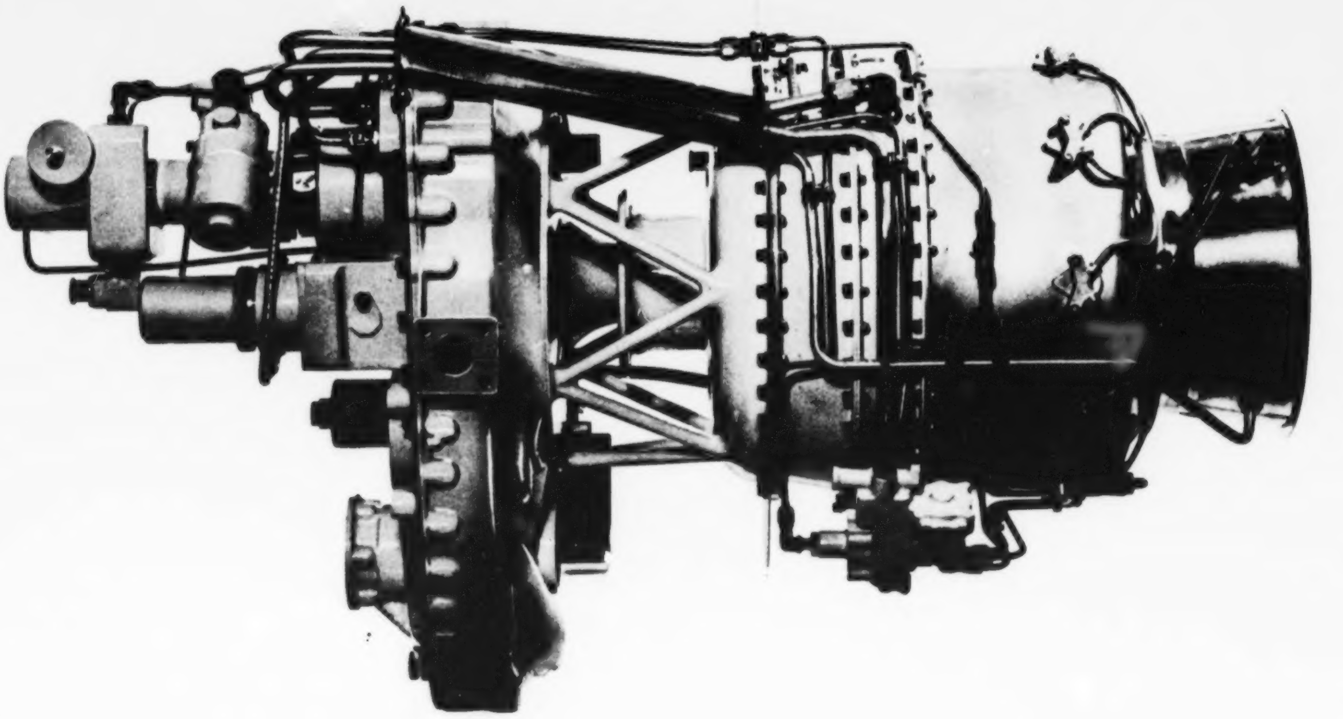
GAS TURBINE SALES

AIRESEARCH MANUFACTURING DIVISION OF ARIZONA, 402 South 36th Street, Phoenix, Arizona 85034

GARRETT/AIRESEARCH

AIRCRAFT ENGINES

TURBOSHAFT
TSE 231



The AiResearch TSE231 is a 400 to 500 horsepower free-turbine turboshaft engine that has been designed to meet the requirements of the modern helicopter. Since the excellent power to weight ratio and specific fuel consumption features were assured, the major development effort was directed toward producing a turbine engine that will be economical to own and operate.

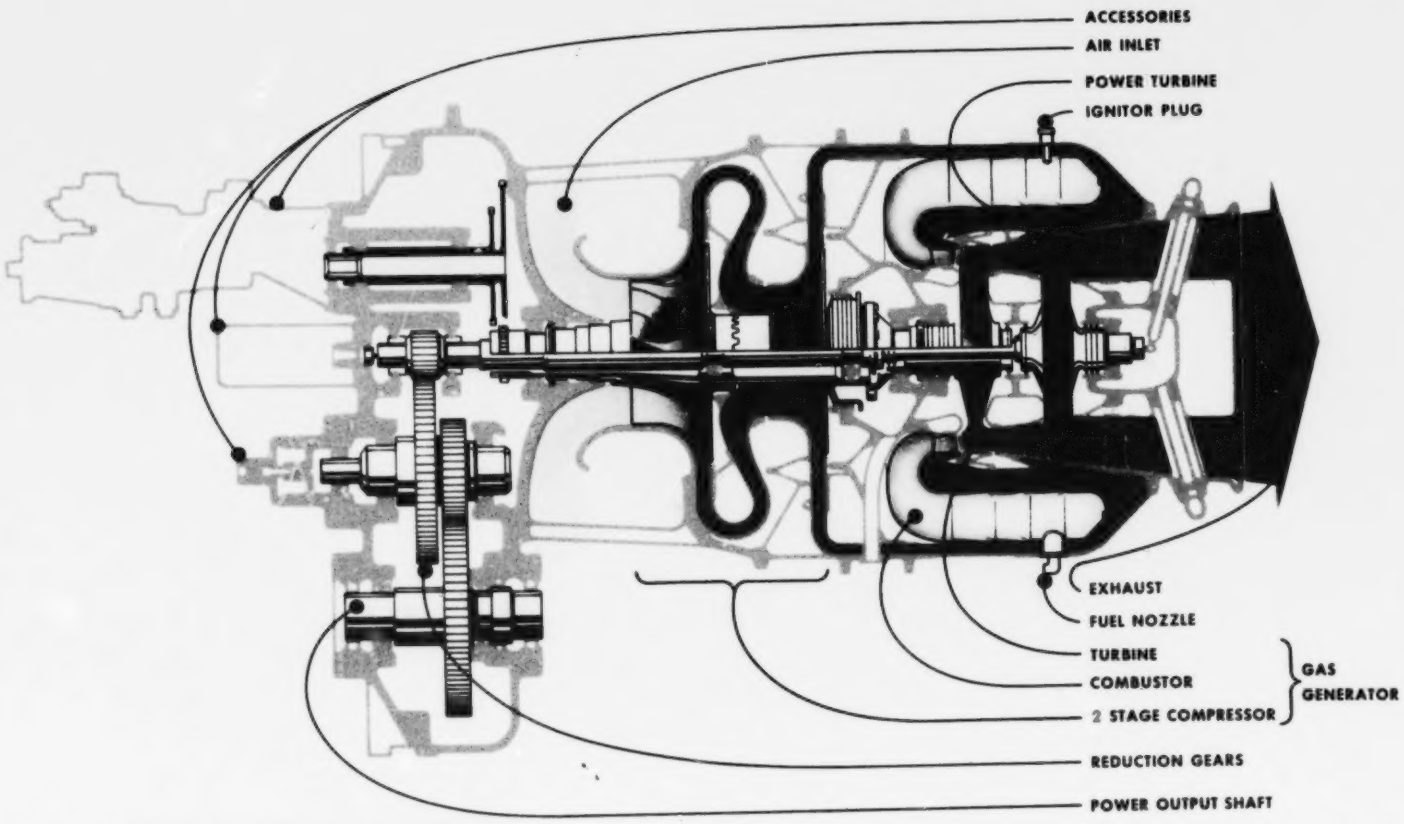
The elements of simplicity and reliability designed into the TSE231 reflect Garrett-AiResearch proven design concepts. Components of the TSE231 power section are scaled down from, or are very similar to, the TPE331/T76 turboprop engine that has demonstrated exceptional performance for over a million flight hours.

A specification and engineering assistance is available to assure satisfaction in selection of a TSE231 for your application.

Call your nearest Garrett office or write directly to Aircraft Engine Sales at—

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
402 SOUTH 36TH STREET, PHOENIX, ARIZONA 85034

TSE 231


ACCESSORIES
AIR INLET
POWER TURBINE
IGNITOR PLUG
EXHAUST
FUEL NOZZLE
TURBINE
COMBUSTOR
2 STAGE COMPRESSOR
GAS GENERATOR
REDUCTION GEARS
POWER OUTPUT SHAFT

ENGINE OPERATION

The AiResearch Model TSE231 is a free-turbine turboshaft engine with an integral dry-sump reduction gearbox. The output shaft centerline is offset from the engine rotor centerline and provides an internally splined output drive at the front and rear of the gearbox.

The gas generator is composed of a two-stage centrifugal compressor directly coupled to a single-stage axial gas generator turbine. Air enters the engine radially around the complete circumference of the compressor inlet. After being compressed, the air enters the combustor section where it picks up heat energy from the burning fuel-air mixture and then is directed through the turbine. The gas coupled power turbine transmits the extracted shaft power through the hollow shaft of the gas generator to the reduction gearbox.

TSE 231 FEATURES

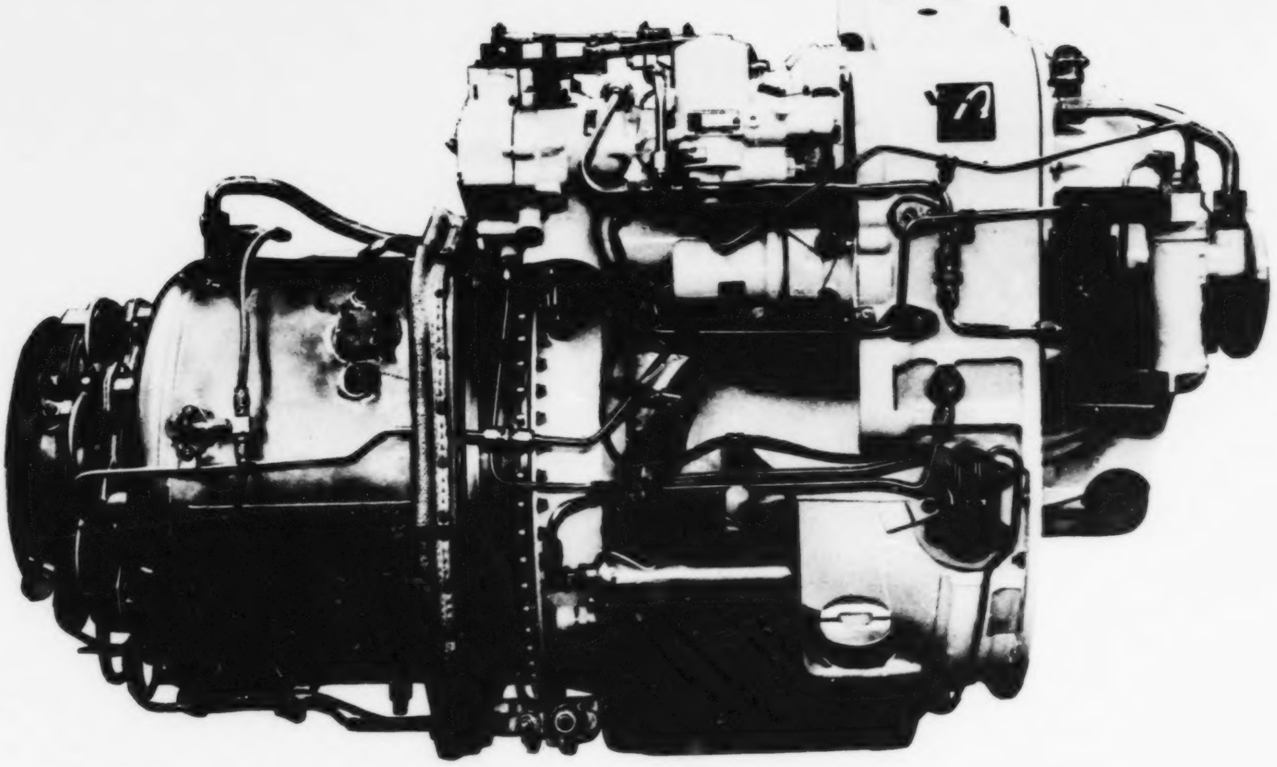
Installation Flexibility	Availability of the main output shaft at the front and rear of the gearbox.
Operating Economy	Good fuel specifics and anticipated time between overhauls will result in low operating costs.
Performance	Power to weight ratio over [illegible] to 1.
Dependable	Rugged centrifugal compressors have proven ability to resist foreign object damage.

GARRETT/AIRESEARCH

AIRCRAFT ENGINES

TURBOPROP

TPE 331



The AiResearch TPE 331 engines were designed to meet requirements for a small, powerful turboprop engine under 1100 HP. In the TPE 331, the low and medium airspeed efficiencies of the propeller are maximized with the quick response, high power, and low weight advantages of the fixed shaft turbine engine. Immediate propeller thrust is available with the added bonus of jet thrust due to the front-to-rear design. The TPE 331 has but two controls: a power and an engine RPM lever. The result is a pilot's engine, simple to operate and easy to manage, requiring less pilot orientation and a minimum of in-flight monitoring.

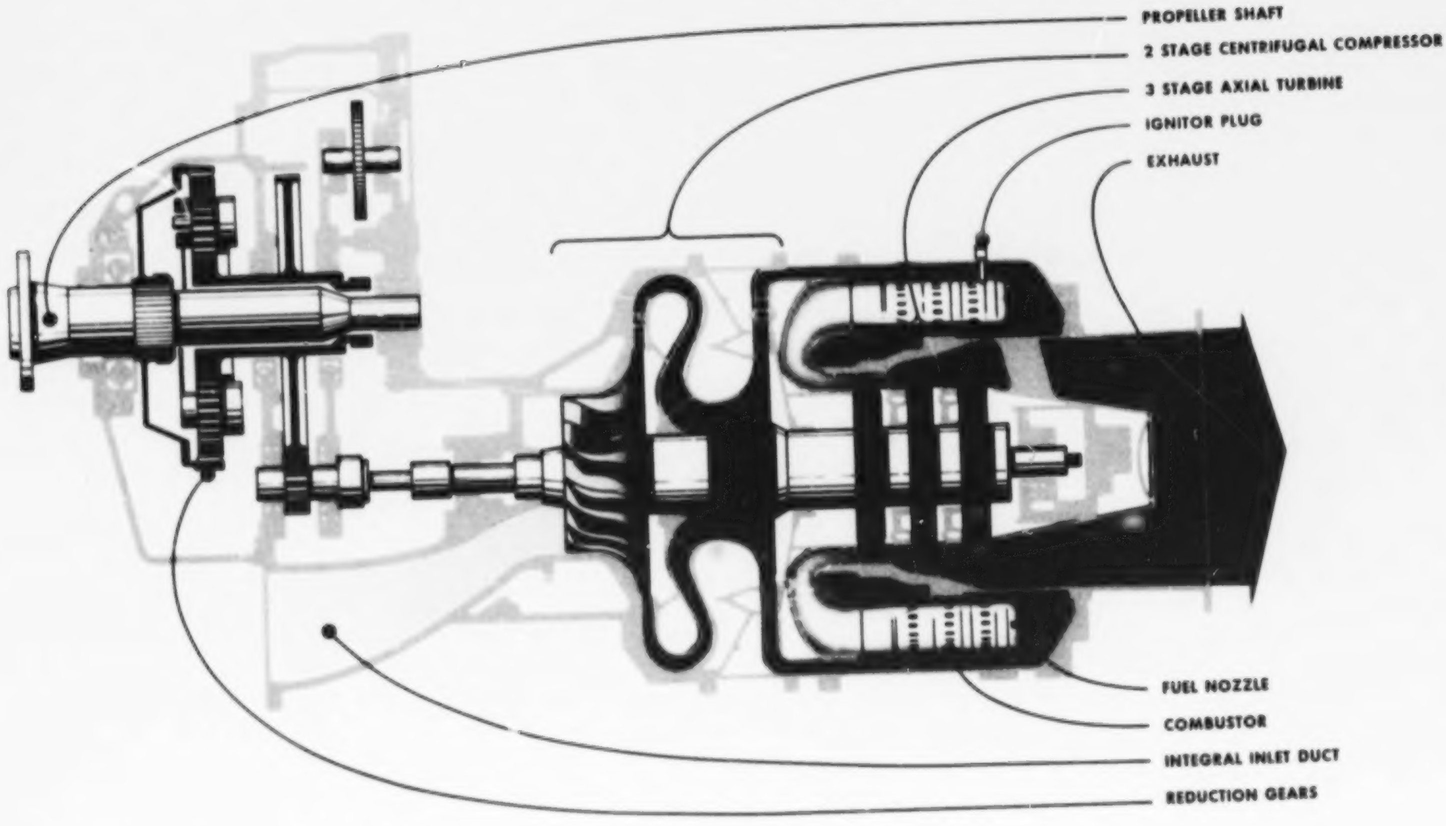
The first certified models of the TPE 331 were rated at 575 HP with later models rated at various levels of growth within the same frame size. A specification, installation manual and engineering assistance is available to assure satisfaction in selection of a TPE 331 for your application.

Call your nearest Garrett office or write directly to Aircraft Engine Sales at—

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
402 SOUTH 36TH STREET, PHOENIX, ARIZONA 85034

MS 2101-4

TPE 331



ENGINE OPERATION

The uncomplicated operational features of the compact TPE 331 are made possible by a totally integrated engine containing a small fixed shaft power section; main shaft reduction gearing; a self-contained power management system, providing for: engine speed control, propeller pitch control (including full reverse), and fuel flow control. The TPE 331 produces power by converting heat energy obtained from fuel combustion to rotating mechanical energy. Air is compressed in a two-stage centrifugal compressor. The compressed air flows into an annular combustion chamber where it is mixed with fuel spray and ignited. After ignition, combustion is sustained. The combustion gases are expanded through a three-stage axial turbine with the resultant energy driving the compressor and the propeller shaft. Automatic compensation provisions are incorporated for atmospheric pressure and temperature variations to provide a smooth operating powerplant under all conditions.

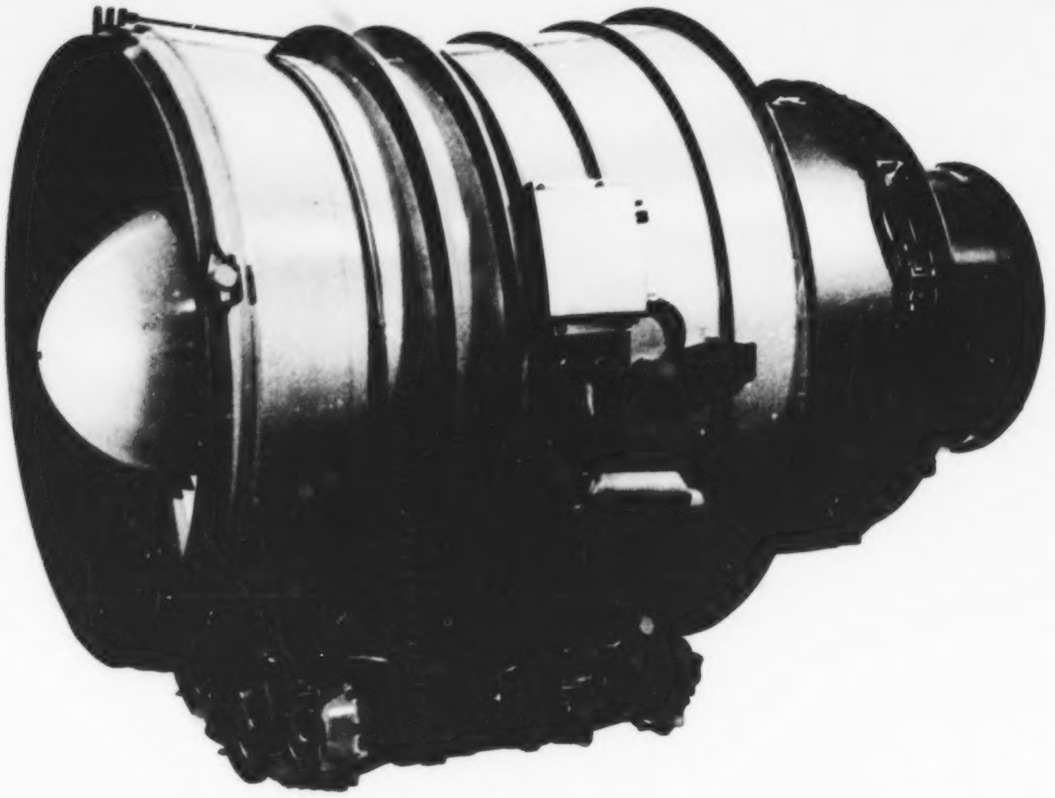
TPE 331 FEATURES

Installation Flexibility	The air inlet is an integral part of the engine and can be positioned above or below the propeller shaft.
Performance	A power to weight ratio of over 2 to 1.
Operating Economy	The low drag profile and reduced fuel costs combined with extended time between overhaul provides lower seat-mile operating costs.
Response	Inherent in a fixed-shaft design is the ability to accept full power in less than one second.
Simplicity	Pilot control is via two basic engine levers. Engine instrumentation is minimum.
Anti-icing	Anti-ice protection of the inlet is accomplished using second stage bleed air.
Reverse Thrust	Propeller reversing is standard equipment and allows an increased measure of ground control.
Negative Torque Sensing	Automatic propeller drag reduction is accomplished by the Negative Torque Sensing System in the event of an engine shutdown.

GARRETT/AIRESEARCH

AIRCRAFT ENGINES

TURBOFAN
TFE 731



The AiResearch TFE731 is a relatively high by-pass ratio, two-spool, geared front fan engine with the design based on performance, reliability, maintainability and operating economy. The use of this two-spool, geared fan arrangement provides not only improved performance at high altitude cruise, but also maintains excellent performance at lower altitudes. This allows flexibility in design of an aircraft to give high speed transcontinental range without sacrificing short field performance. The basic aerodynamic design of components is derived from proven production components that have demonstrated excellent performance and life over many years of AiResearch turbine engine operation.

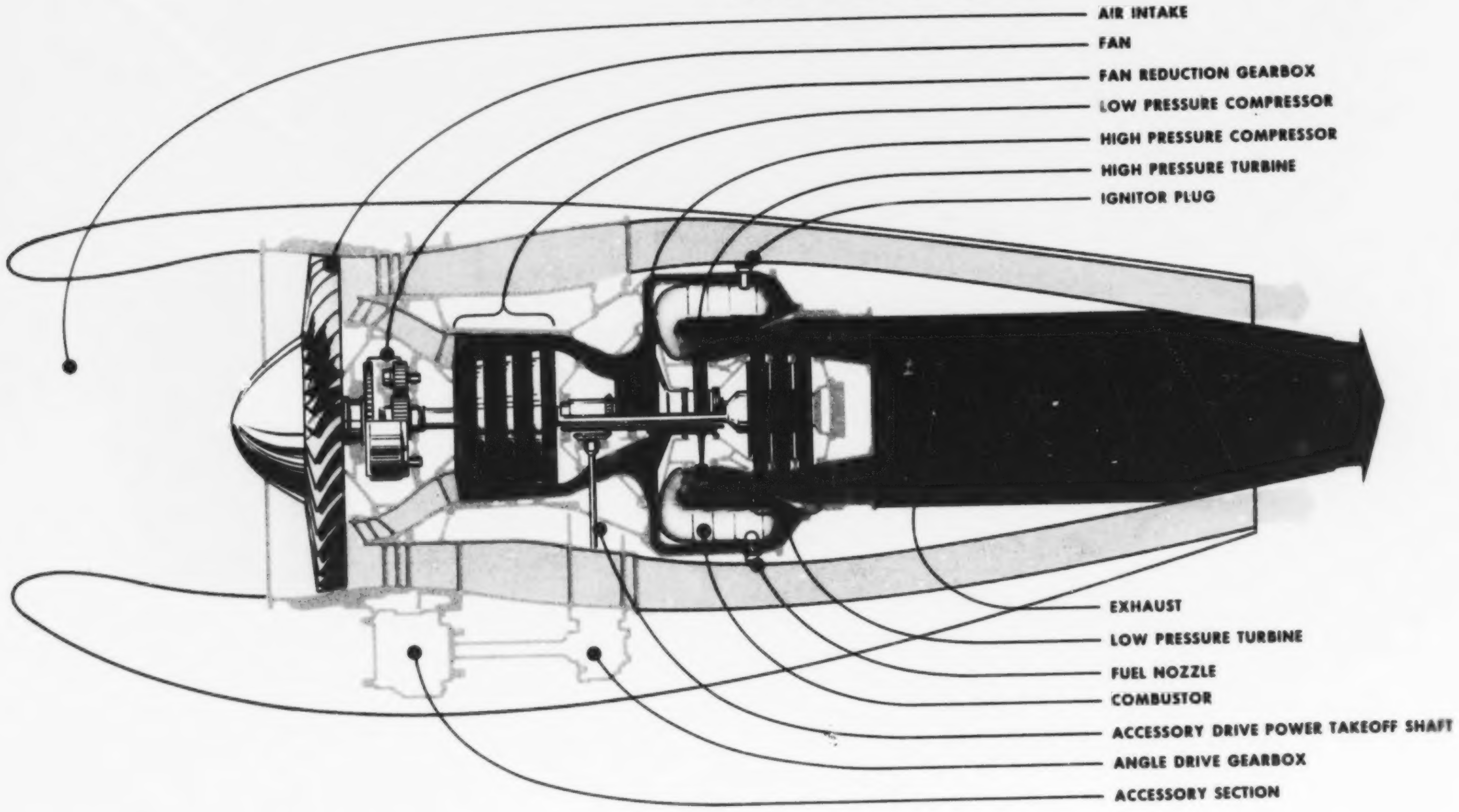
A specification, installation manual and engineering assistance is available to assure satisfaction in the installation of a TFE731 in your application.

Call your nearest Garrett office or write directly to Aircraft Engine Sales at—

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
402 SOUTH 36TH STREET, PHOENIX, ARIZONA 85034

MS 2101-5

TFE 731


AIR INTAKE
FAN
FAN REDUCTION GEARBOX
LOW PRESSURE COMPRESSOR
HIGH PRESSURE COMPRESSOR
HIGH PRESSURE TURBINE
IGNITOR PLUG
EXHAUST
LOW PRESSURE TURBINE
FUEL NOZZLE
COMBUSTOR
ACCESSORY DRIVE POWER TAKEOFF SHAFT
ANGLE DRIVE GEARBOX
ACCESSORY SECTION

ENGINE OPERATION

Air from the nacelle diffuser section enters the single stage geared fan of the TFE731. The largest portion of the air goes to the bypass duct and the remainder is directed into the low pressure, four-stage axial compressor. It then passes through the centrifugal compressor of the high pressure spool on its way to the combustor where it picks up the heat energy of the burning fuel/air mixture. The hot gases drive the high pressure single-stage axial turbine and then expand to atmosphere through the low pressure spool, three-stage axial turbine and exhaust nozzle. The high pressure spool is geared to drive the reduction gearbox and the engine accessories. The engine exhaust geometry is arranged for operation with separately ducted customer-furnished thrust nozzles for fan and turbine discharge flows.

TFE 731 FEATURES

High performance with minimum number of aerodynamic components

Excellent operating economy and range

High thrust to weight ratio of 5.00

Low cost, rugged, reliable construction

Ease of maintenance

External accessories

Anti-icing provision for all weather capability

No variable geometry complexities

Low noise level with no fan inlet guide vanes

Adaptable for thrust reversing

Conservative turbine inlet temperatures

Continuous duty ignition

Combustion system for low contaminant emission.

Growth potential of 25% to 30%

4. DESCRIPTION OF TEST

The gas turbine exhaust emissions measurement tests were conducted at the AiResearch, Phoenix, test laboratories during the months of April, May, and June 1971. Thirty-two AiResearch commercial gas turbine engines were tested. These include 26 auxiliary power and 6 aircraft propulsion gas turbine engines. Table 4 lists the specific engine models tested in chronological order together with the aviation turbine fuels used, number of power settings or load conditions, and the number of probe locations from which gas samples were extracted at the exit plane of the engine tailpipe.

On several occasions a particular engine model was not available from production, development or overhaul for a scheduled test. An engine substitution was possible by obtaining for test the equivalent military engine counterpart. Each unit belongs to the same engine series and therefore have identical power section components and cycle characteristics. Usually, only the performance rating and/or the external configuration is the primary difference between these engines. Thus it was possible to substitute the GTCP85-180 military engine for the GTCP85-98CK commercial engine simply by operating at a lower engine speed. Similarly, the T76 military engine was substituted for the TPE331-201A turboprop engine.

The tests were conducted in accordance with the test procedure contained in GT-8713-R except as noted in subsequent paragraphs. Emission measurements were performed on the engines at essentially sea level, static operating conditions. Prevailing engine inlet air temperatures ranged from 70°F to 110°F, with an average relative humidity of 16 percent. Special test equipment was required in addition to the test equipment and instrumentation normally used for engine acceptance tests: A description of the special test equipment is as follows:

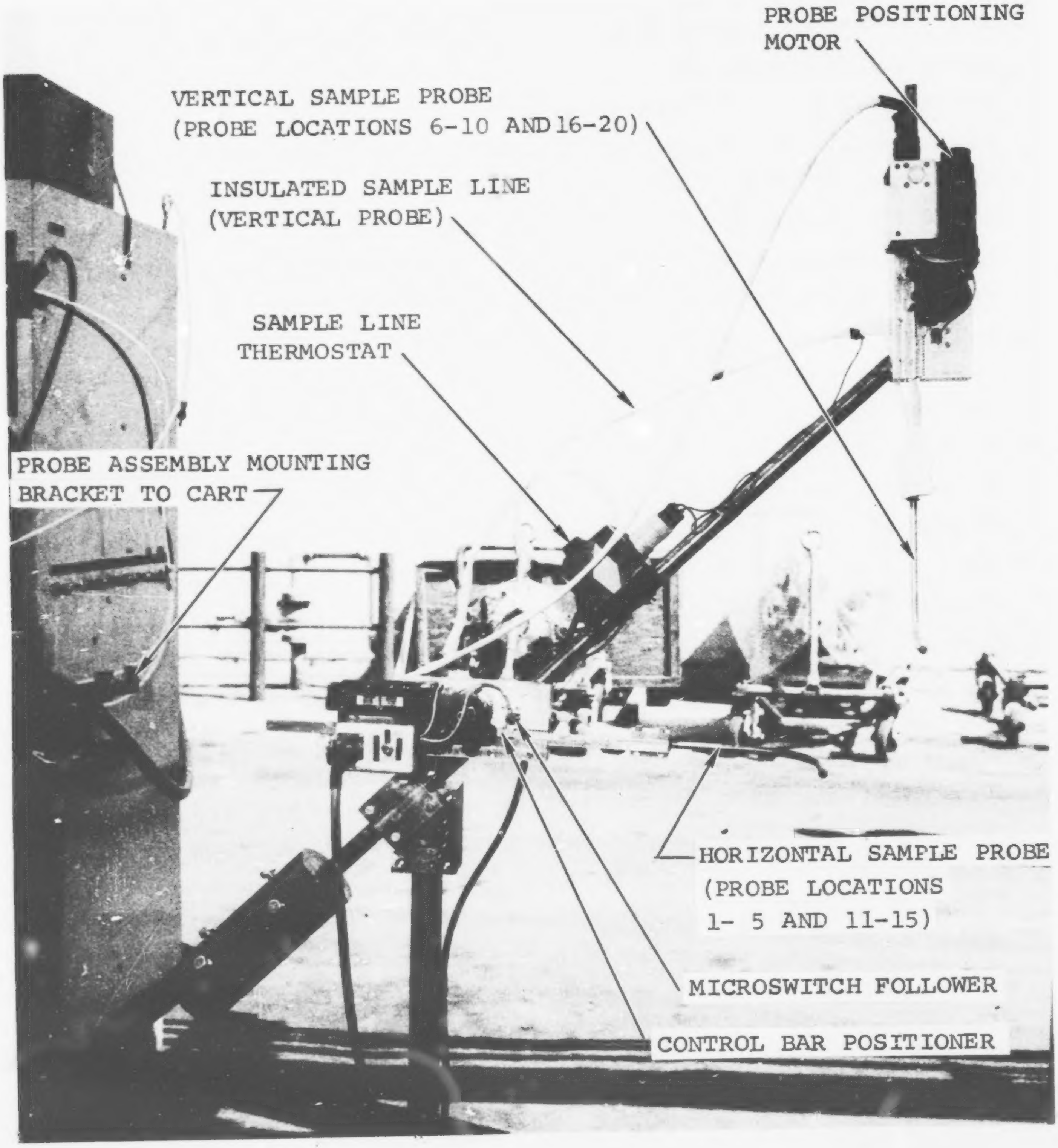
TABLE 4

GAS TURBINE ENGINES SURVEYED IN EMISSIONS MEASUREMENT TEST PROGRAM

	Engine Model	Test Unit From	Serial No.	Test Date	Fuel	No. of Power Settings	No. of Probe Locations
1.	GTCP85-129	O/H	P-34763	4-29	JP-5	10	10
2.	TPE331-1-151G	P	P-91168	5-1	JP-5	6	10
3.	GTCP85-98D	O/H	P-27692	5-3	JP-5	10	10
4.	GTCP85-90B	P	P-24504	5-5	JP-4	6	10
5.	T-76-G-410	O/H	G.E. 00790 (P for 2 weeks)	5-6	JP-5	6	10
6.	GTCP85-98D	O/H	P-27857	5-7	JP-5	10	10
7.	TPE331-43A	O/H	P-61157	5-11	JP-4	2	10
					JP-5	6	10
8.	GTCP85-115	O/H	P-18725	5-13	JP-5	10	10
9.	GTCP36-6	O/H	P-34772	5-14	JP-5	8	10
10.	GTCP36-6	O/H	P-34696	5-14	JP-5	6 (Plus bleed-air)	10
11.	GTCP85-98	O/H	P-15454	5-17	Av kero	10	10
12.	GTCP30-92	O/H	P-28794	5-17	Av kero	10	10
13.	GTCP30-92 (Vaporizer)	O/H	P-28794	5-18	Av kero	10	10
14.	GTCP85-98	O/H	P-15257	5-18	Av kero	10	10
15.	GTCP85-90	O/H	P-5786	5-19	Av kero	5	20
16.	GTCP85-98	O/H	P-15541	5-21	Av kero	10	10
17.	TSCP700-4	P	P-90122	5-24	JP-5	12	10
18.	GTCP660-4	P	P-37705	5-25	JP-5	10	10
19.	GTCP660-4	O/H	P-37536	5-26	JP-5	11	10
20.	TSCP700-4	P	P-90123	5-27	JP-5	12	10
21.	TPE331-1-151G	O/H	P-91165	6-1	Av kero	6	10
22.	GTCP85-98CK	O/H	P-35648	6-7	Av kero	10	10
23.	GTCP85-115	O/H	P-18781	6-8	Av kero	10	10
24.	TFE731-2	D	7305	6-10	Av kero	6 (Smoke samples)	10
25.	GTCP85-115	O/H	P-18702	6-11	Av kero	10	10
26.	GTCP85-180	P	P-567	6-14	Av kero	10	10
27.	GTCP85-180	P	P-507	6-14	Av kero	10	10
28.	GTCP85-180 (98CK)	P	P-518	6-15	Av kero	10	10
29.	GTCP85-180 (98CK)	P	P-595	6-15	Av kero	10	10
30.	GTCP85-180 (98CK)	P	P-593	6-16	Av kero	11 (NO_x ice bath test)	10
31.	GTCP85-90B	O/H	P-24376	6-16	JP-5	5 (12 point probe)	12
32.	TSE231-1	D	2301	6-18	Av kero	6	10

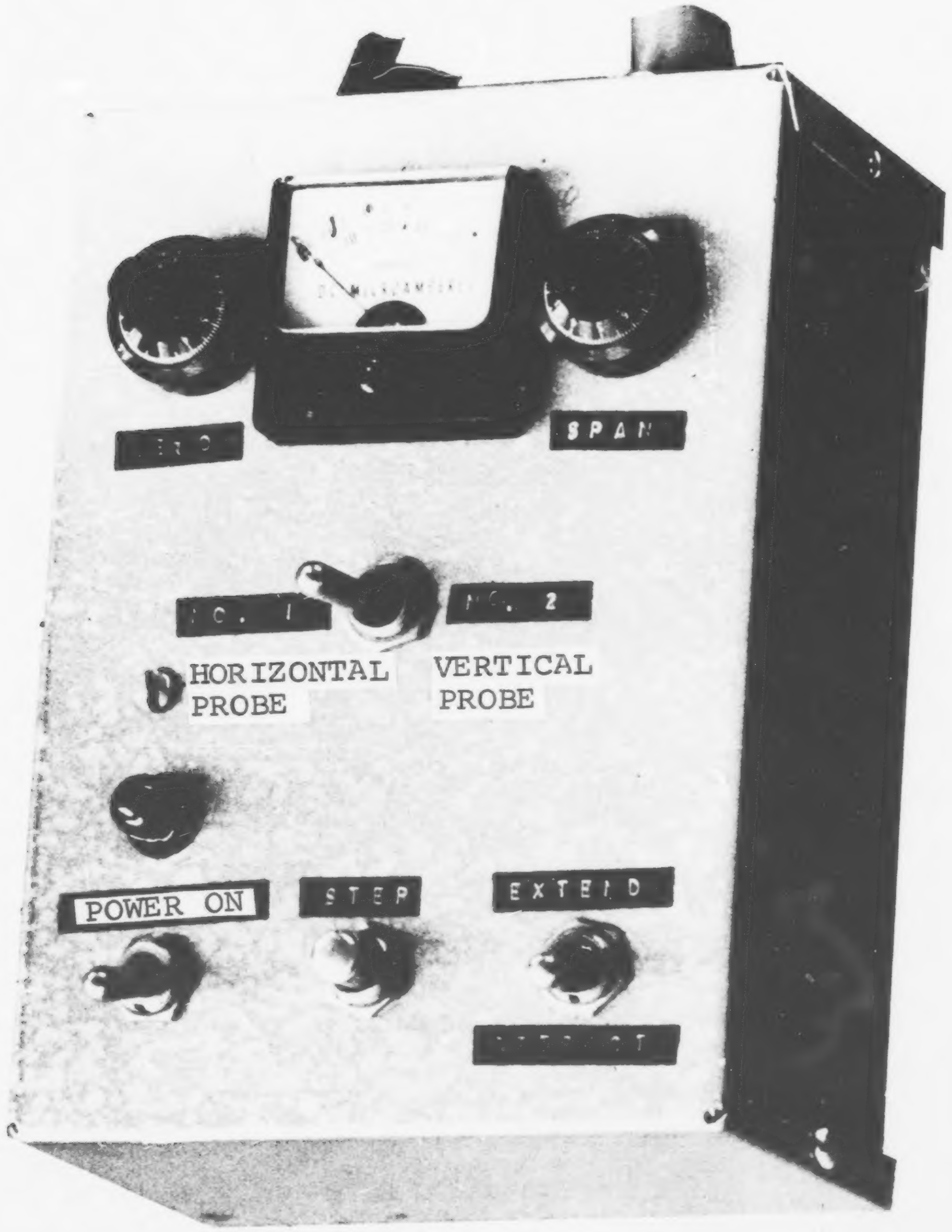
Abbreviation Key: O/H = Overhaul, P = Production, D = Development, Av kero = Aviation kerosene (jet A)

Sample Probe Assembly, SKP26000 - Figures 6 and 7 shows the sample probe assembly and its control box which permitted the operator to actuate the probes from a remote area. The assembly is comprised of two adjustable single point probes, one to survey the vertical and the other to survey the horizontal radii of the engine tailpipe. Each are mounted on the same support stand, SKP26093, shown in Figure 6. Each probe could be translated by a drive motor to each of five positions along a given radii in the engine exhaust exit plane 90 deg apart and may be reversed to pickup an additional 10 gas samples. Figure 8 shows the movable probe locations as assigned to a radial clock position, illustrated on a TPE331 engine test setup. Each probe was center-positioned in each of five equal annulus areas. Since each engine series has different tailpipe areas, a control bar for each was designed with machined slots corresponding to the precise probe location desired within each of 5 equal annulus areas determined for each engine tailpipe area. An appropriate control bar was then attached to each sample probe and mated to the drive train of the probe actuator motor. Probe advance was controlled by a microswitch that followed the control bar between machined slots in the bar, thereby providing an electrical step input for each successive advance once energized by the remote control box. A position indicator was mounted on each probe to indicate the probe position at any time. A three-way solenoid actuated valve joining the horizontal and vertical sample gas lines was automatically thrown each time either the horizontal or vertical drive motor was energized thereby permitting only gas sample flow from the desired probe to reach the gas analyzer instrumentation on the test cart at a given time.


PROBE POSITIONING MOTOR
VERTICAL SAMPLE PROBE (PROBE LOCATIONS 6-10 AND 16-20)
INSULATED SAMPLE LINE (VERTICAL PROBE)
SAMPLE LINE THERMOSTAT
PROBE ASSEMBLY MOUNTING BRACKET TO CART
HORIZONTAL SAMPLE PROBE (PROBE LOCATIONS 1- 5 AND 11-15)
MICROSWITCH FOLLOWER
CONTROL BAR POSITIONER

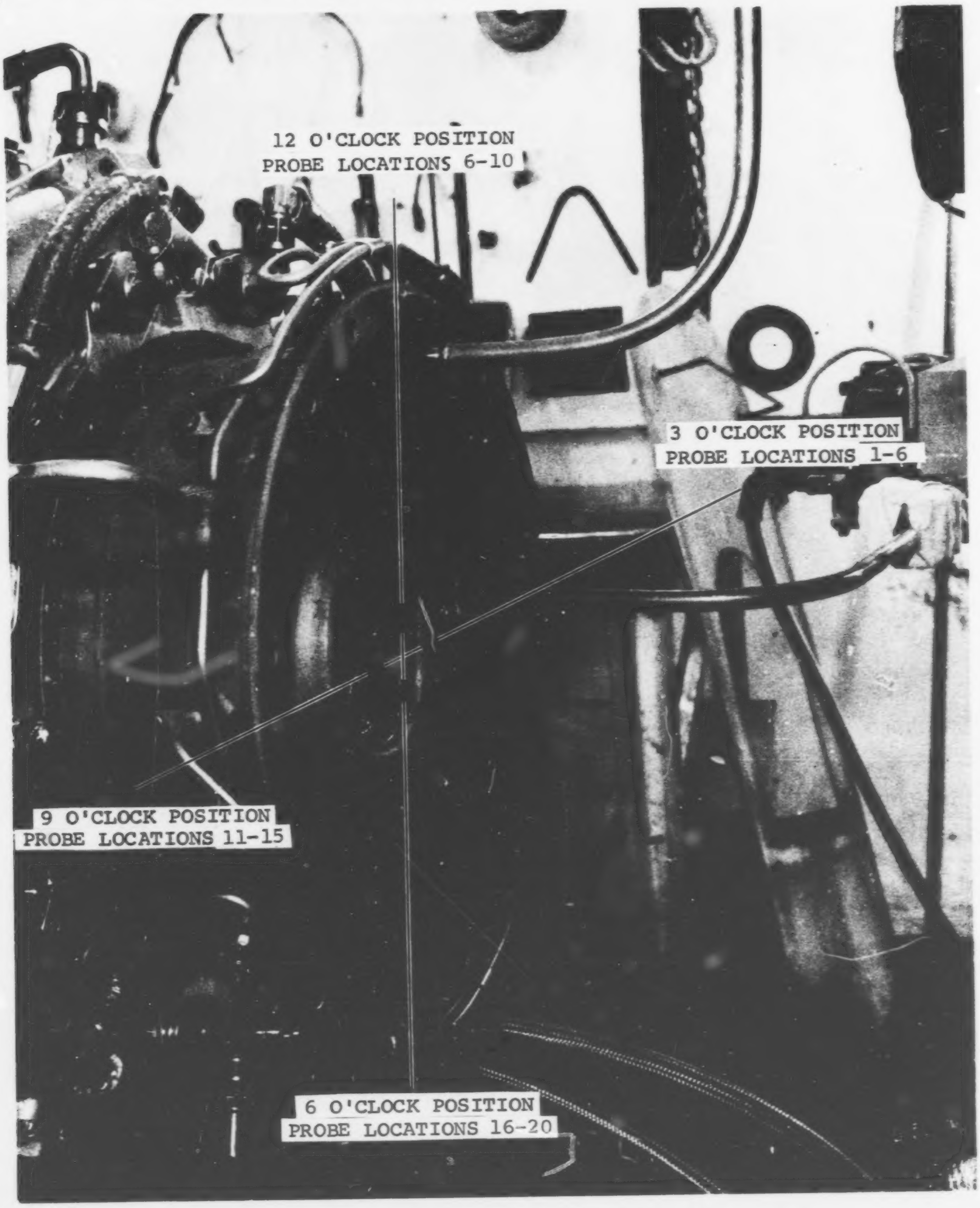
EMISSIONS MEASUREMENT MOVABLE
PROBE ASSEMBLY

Figure 6


SPAN
NO. 1
NO. 2
HORIZONTAL PROBE
VERTICAL PROBE
POWER ON
STEP
EXTEND

CONTROL BOX FOR MOVABLE
SINGLE-POINT PROBES

Figure 7


12 O'CLOCK POSITION
PROBE LOCATIONS 6-10
3 O'CLOCK POSITION
PROBE LOCATIONS 1-6
9 O'CLOCK POSITION
PROBE LOCATIONS 11-15
6 O'CLOCK POSITION
PROBE LOCATIONS 16-20

MOVABLE PROBE LOCATIONS AS ASSIGNED
TO A RADIAL CLOCK POSITION ILLUSTRATED ON
A TPE331 ENGINE TEST SETUP

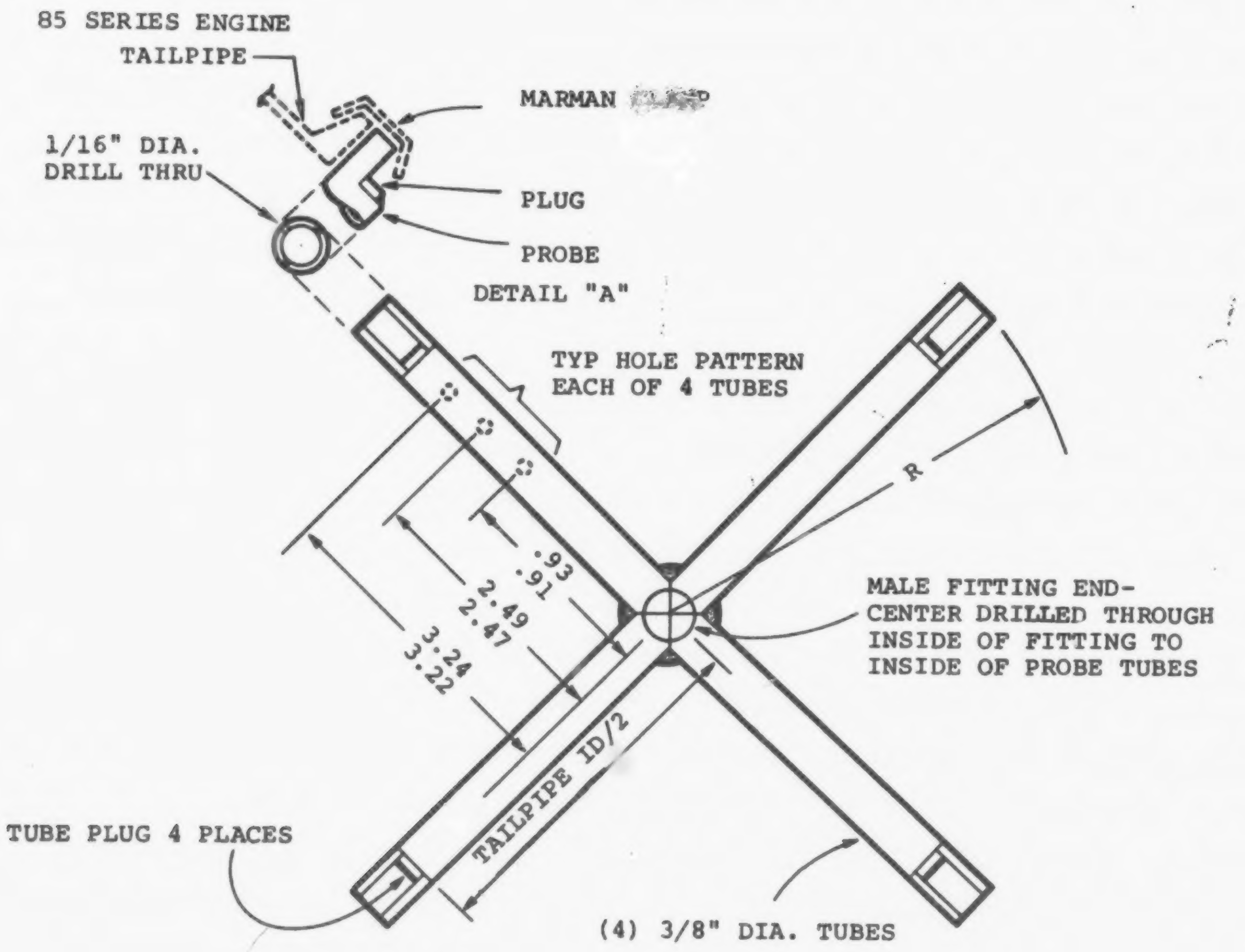
FIGURE 8

MP-30231

A 24 volt dc power supply available from the test cell was required to actuate the probe drive motors. Also, a 110 volt ac power supply was wired to the probe support stand to energize the electrical strip heaters wrapped around the gas sample lines to minimize adsorption/desorption of hydrocarbon molecules in the sample lines. Similarly, the 10 foot gas sample line made from 3/16 in. inside diameter, stainless steel tubing, leading to the instrumentation test cart was heated to a temperature of approximately 310°F to minimize the same physical property hydrocarbons exhibit of adhering to the walls of the sample line.

All engines were tested using the movable probe, while several turbine emissions measurement programs conducted outside of AiResearch were using a fixed probe approach to emissions measurement. Consequently, AiResearch designed a similar fixed probe to compare test results obtained using both the movable and fixed probe measuring techniques on the same engine. The design was made specifically for the 85 Series engines and incorporates 3 sampling points in each of 4 branches which are manifolded to a single sample line as shown in Figures 9 and 10. Each sample collection point lies centered within equal annulus tailpipe areas. Figure 10 shows the probe mounted to a GTC85-90B gas turbine using a standard Marman clamp. Twelve-point movable versus 12-point fixed (average) and 6-point movable versus 12-point movable sample data were collected on this engine. Comparisons of the resultant emissions measurements were made and are included in the following section of discussion of test results.

Portable gaseous emissions measurement instrumentation as provided by the Office of Air Programs, Environmental Protection Agency are shown mounted on an AiResearch designed mobile test cart in Figures 11, 12, and 13. All gas analyzer instruments,

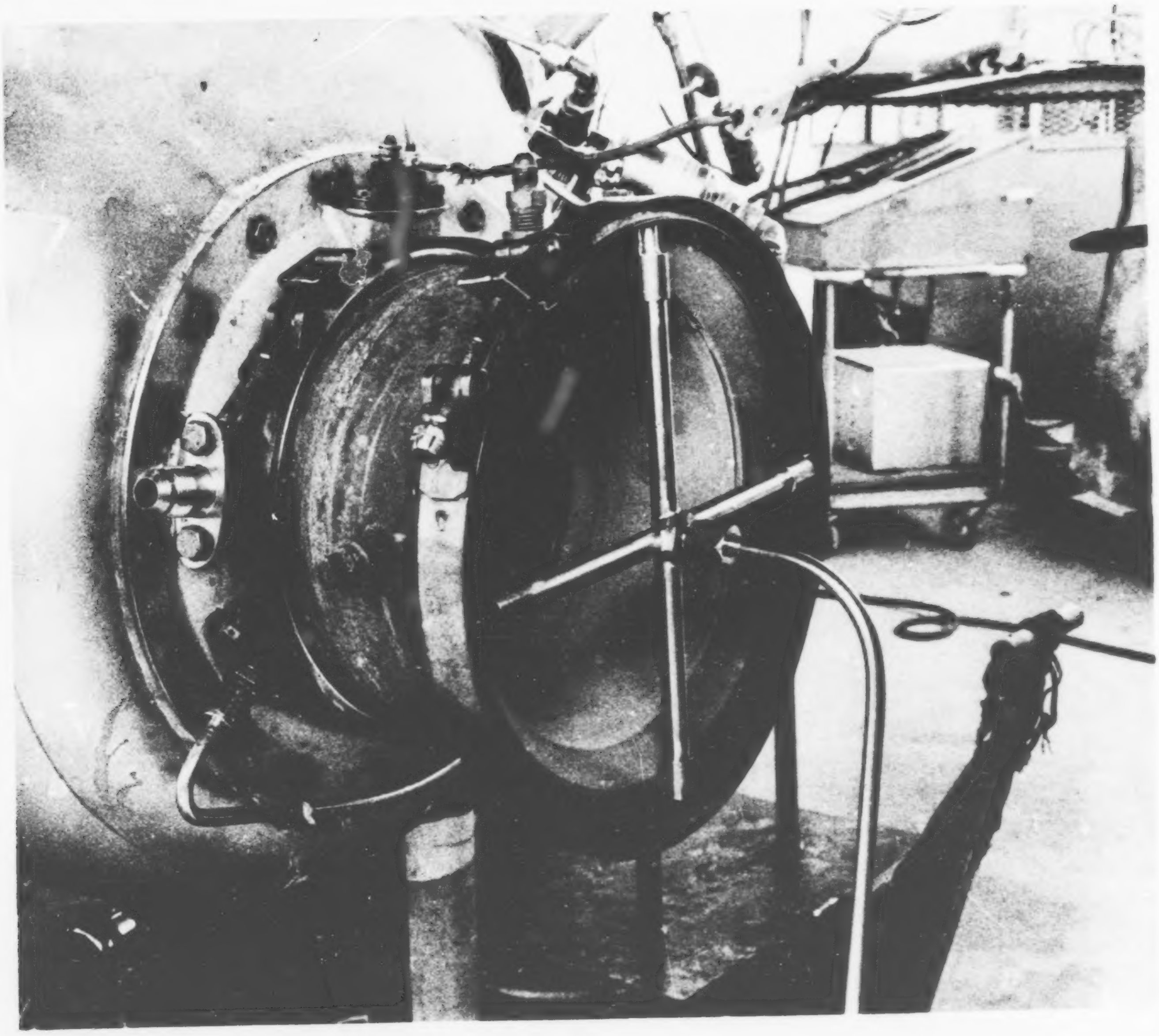

85 SERIES ENGINE
TAILPIPE
MARMAN CLAMP
1/16" DIA.
DRILL THRU
PLUG
PROBE
DETAIL "A"
TYP HOLE PATTERN
EACH OF 4 TUBES
R
.93
.91
2.49
2.47
3.24
3.22
MALE FITTING END-
CENTER DRILLED THROUGH
INSIDE OF FITTING TO
INSIDE OF PROBE TUBES
TAILPIPE ID/2
TUBE PLUG 4 PLACES
(4) 3/8" DIA. TUBES

MATERIAL: 347 STAINLESS STEEL

NOTE:

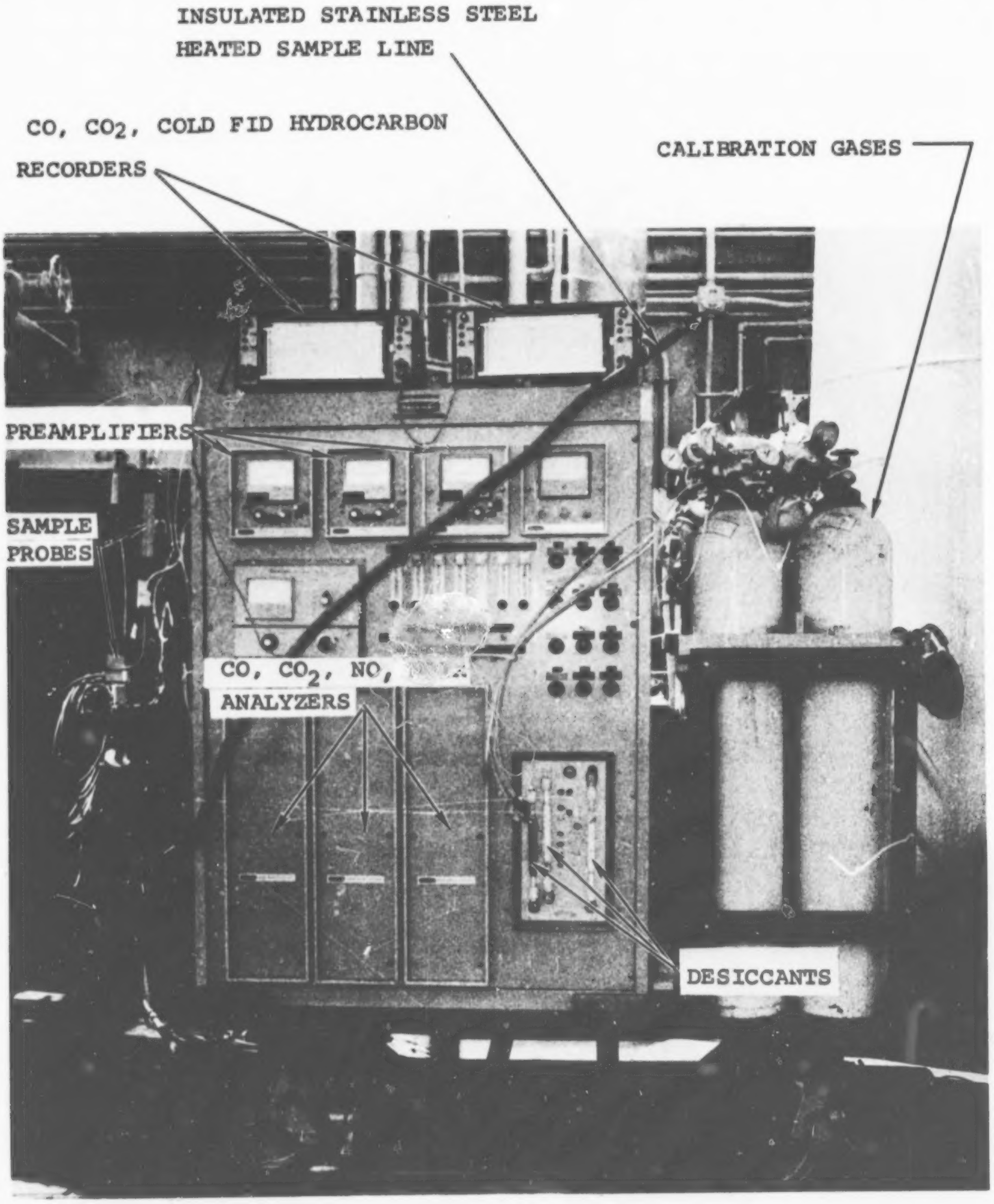
1. PROBE DIAMETER, 2R, SIZED SO THAT IT CAN BE HELD TO TAILPIPE BY A MARMAN CLAMP (SEE DETAIL "A").

EXHAUST EMISSIONS 12-POINT FIXED
SAMPLING PROBE ASSEMBLY
FIGURE 9



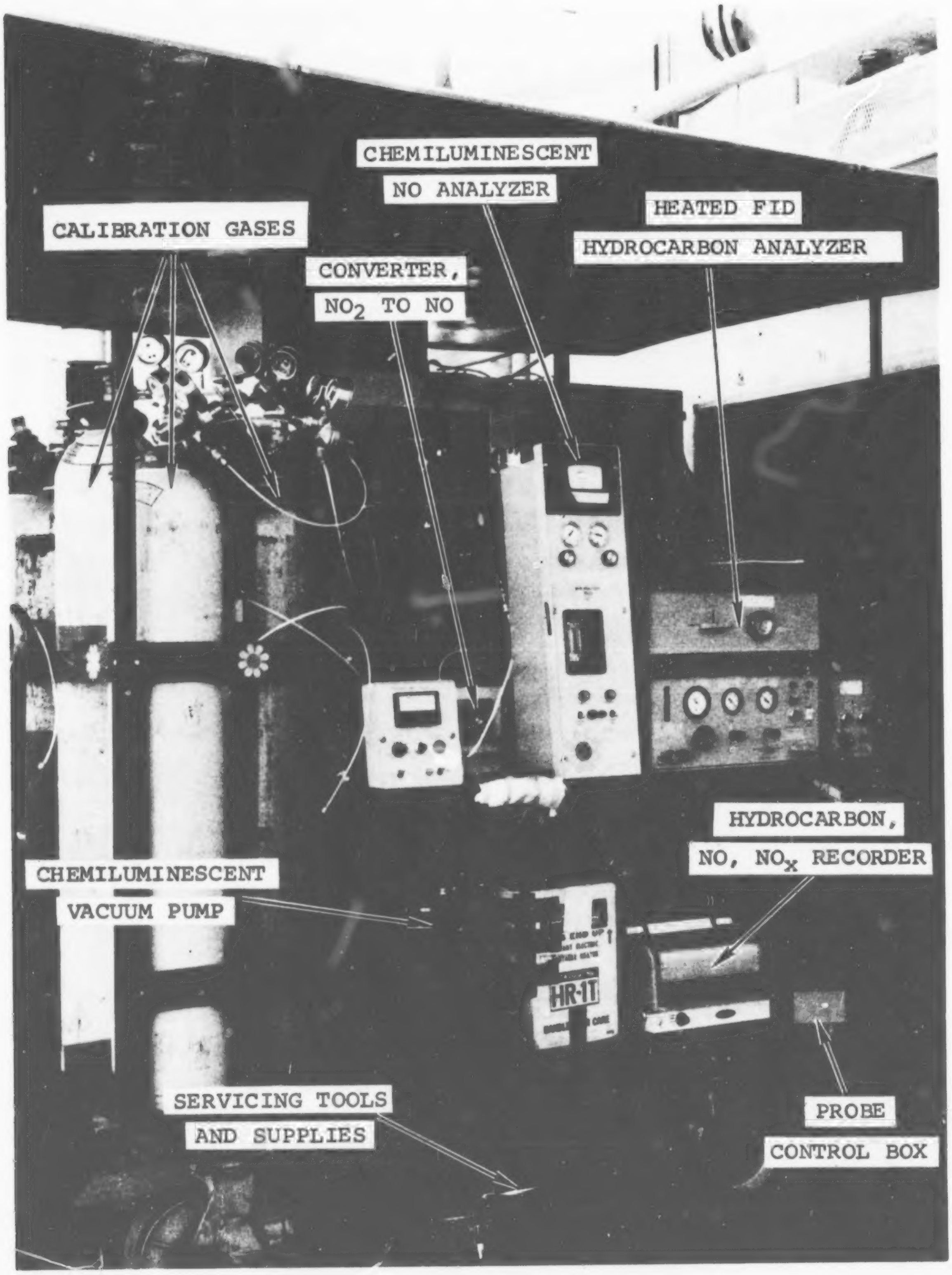
GTC85-90B EXHAUST EMISSIONS
MEASUREMENT BY FIXED PROBE INSTALLATION

Figure 10


INSULATED STAINLESS STEEL
HEATED SAMPLE LINE
CO, CO_2, COLD FID HYDROCARBON
RECORDERS
CALIBRATION GASES
PREAMPLIFIERS
SAMPLE
PROBES
CO, CO_2, NO, [illegible]
ANALYZERS
DESICCANTS

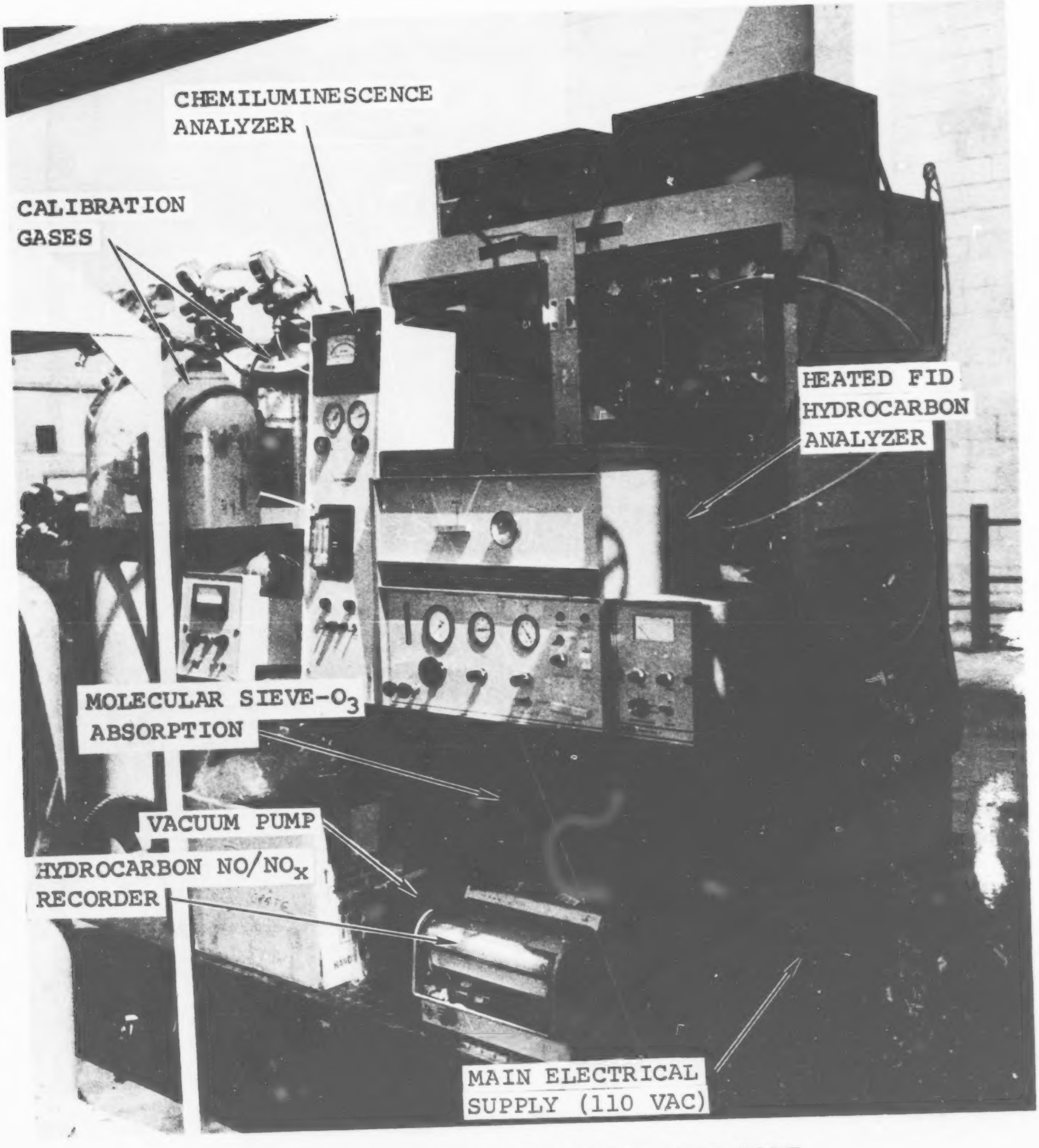
EMISSIONS MEASUREMENT TEST CART
ANALYZERS, RECORDERS, AND CALIBRATION GASES
WITH PROBE ASSEMBLY

Figure 11


CHEMILUMINESCENT
NO ANALYZER
HEATED FID
HYDROCARBON ANALYZER
CALIBRATION GASES
CONVERTER,
NO2 TO NO
HYDROCARBON,
NO, NOx RECORDER
CHEMILUMINESCENT
VACUUM PUMP
HR-IT
SERVICING TOOLS
AND SUPPLIES
PROBE
CONTROL BOX

EMISSIONS MEASUREMENT TEST CART WITH ANALYZERS, RECORDERS, AND CALIBRATION GASES

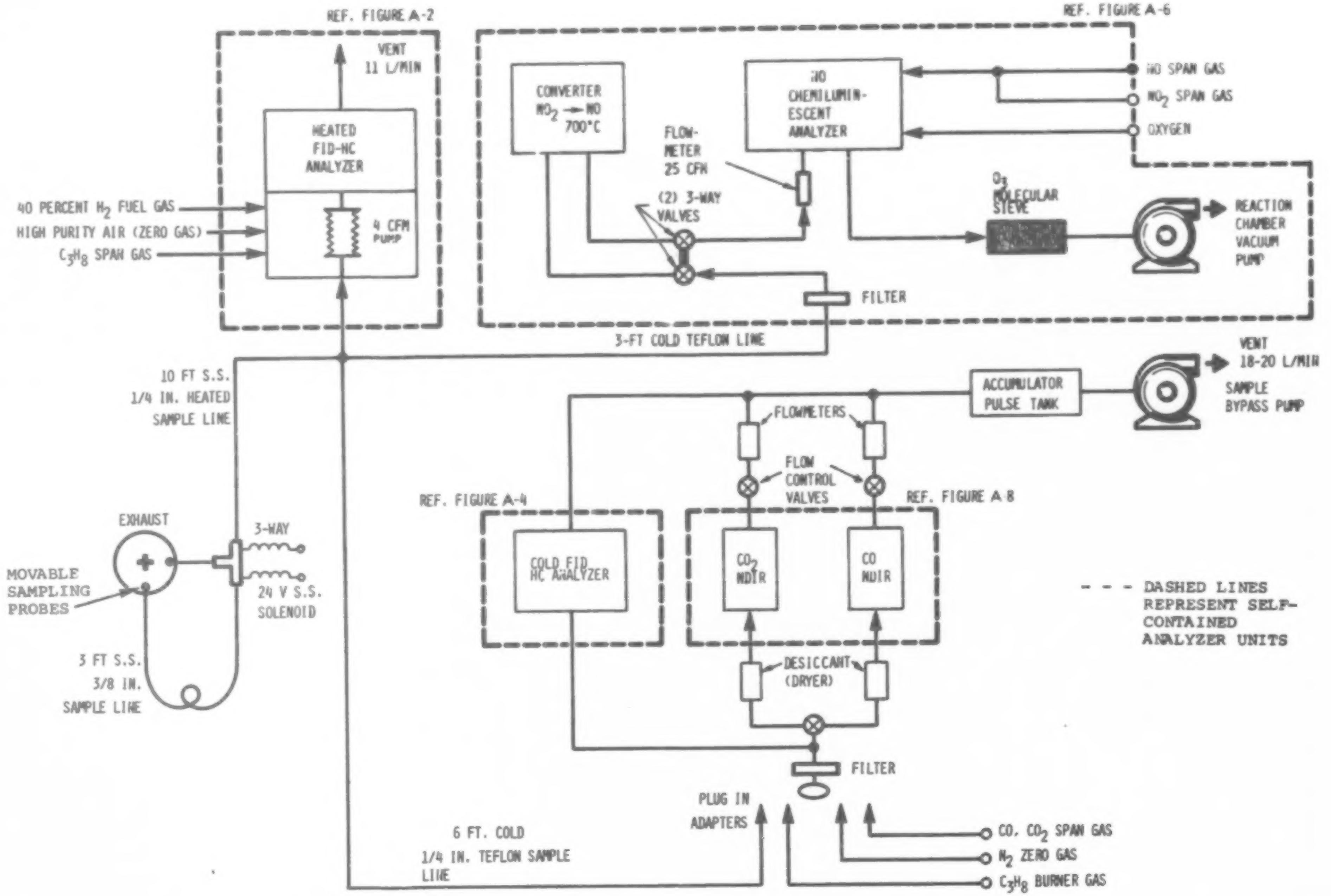
Figure 12


CHEMILUMINESCENCE ANALYZER
CALIBRATION GASES
HEATED FID HYDROCARBON ANALYZER
MOLECULAR SIEVE-O_3 ABSORPTION
VACUUM PUMP
HYDROCARBON NO/NO_x RECORDER
MAIN ELECTRICAL SUPPLY (110 VAC)

EMISSIONS MEASUREMENT TEST CART
ANALYZERS, RECORDERS, AND CALIBRATION GASES
Figure 13

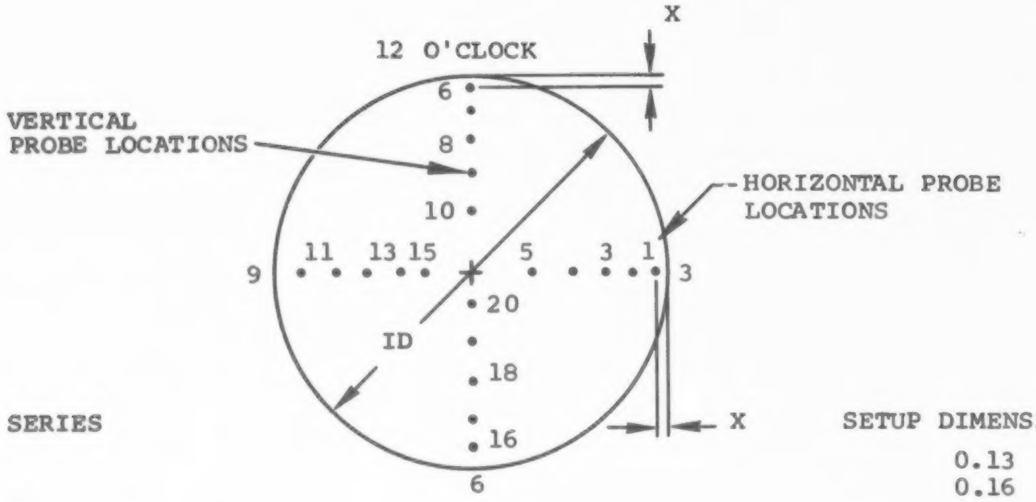
tanks of calibration gases, vacuum pumps, recorders, and servicing tools are installed on the test cart. Figure 14 shows a schematic diagram of the final integrated system as setup for continuous on-line gas sampling and automatic recording of emissions measurements. Exhaust gaseous emissions were measured by the following instrumentation. Two nondispersive infrared analyzers (NDIR) were used for the measurement of carbon dioxide and carbon monoxide. A heated flame ionization detector (FID) measured the emission of total unburned hydrocarbons. The nitric oxide emissions were measured by a chemiluminescent analyzer (CNOA), and a thermal converter was employed to convert the nitrogen dioxide to nitric oxide so that the concentration of total oxides of nitrogen was also indicated. A technical description of each gas analyzer instrument is included as Appendix A of this report.

With the background information regarding special test equipment provided above, attention will be directed toward describing the general test procedure applied to each engine. Each unit was installed in a normal acceptance test configuration. The movable sampling probe assembly was then setup as instructed in Figures 15 and 16. The engine was started and loaded over a range of power settings or load conditions consistent with the application duty cycle for that engine. For example, a typical load range was from idle (no-load, governed speed) to maximum shaft load at zero bleed or from idle to maximum bleed air extraction and zero shaft load. Also, combined bleed/shaft loads were run on several engines. Maximum load limits for this test program are shown in Table 5 followed by the estimated limiting exhaust gas temperature, EGT as shown in Table 6 for each mode of operation. Once steady-state operation was achieved at a given load condition, the exhaust emissions were sampled by the movable sampling probe apparatus and measured by the gas analyzer instrumentation in the manner previously described. Exhaust emissions were


REF. FIGURE A-2
VENT 11 L/MIN
HEATED FID-HC ANALYZER
4 CFM PUMP
40 PERCENT H_2 FUEL GAS
HIGH PURITY AIR (ZERO GAS)
C_3H_8 SPAN GAS
REF. FIGURE A-6
CONVERTER NO_2 → NO 700°C
FLOW-METER 25 CFM
(2) 3-WAY VALVES
NO CHEMILUMIN-ESCENT ANALYZER
NO SPAN GAS
NO_2 SPAN GAS
OXYGEN
O_3 MOLECULAR SIEVE
REACTION CHAMBER VACUUM PUMP
FILTER
3-FT COLD TEFLON LINE
10 FT S.S. 1/4 IN. HEATED SAMPLE LINE
VENT 18-20 L/MIN
ACCUMULATOR PULSE TANK
SAMPLE BYPASS PUMP
FLOWMETERS
FLOW CONTROL VALVES
REF. FIGURE A-4
COLD FID HC ANALYZER
REF. FIGURE A 8
CO_2 NDIR
CO NDIR
DESICCANT (DRYER)
FILTER
EXHAUST
MOVABLE SAMPLING PROBES
3-WAY
24 V S.S. SOLENOID
3 FT S.S. 3/8 IN. SAMPLE LINE
PLUG IN ADAPTERS
6 FT. COLD 1/4 IN. TEFLON SAMPLE LINE
CO, CO_2 SPAN GAS
N_2 ZERO GAS
C_3H_8 BURNER GAS
- - - DASHED LINES REPRESENT SELF-CONTAINED ANALYZER UNITS

SCHEMATIC DIAGRAM FOR EMISSIONS
MEASUREMENT INSTRUMENTATION ON MOBILE CART

Figure 14



ENGINE SERIES	SETUP DIMENSION - X
30	0.13
36	0.16
85, 95	0.21
831	0.23
165	0.19
700	0.26
660	0.34
T76, 331	0.24
731	0.28
231	0.18

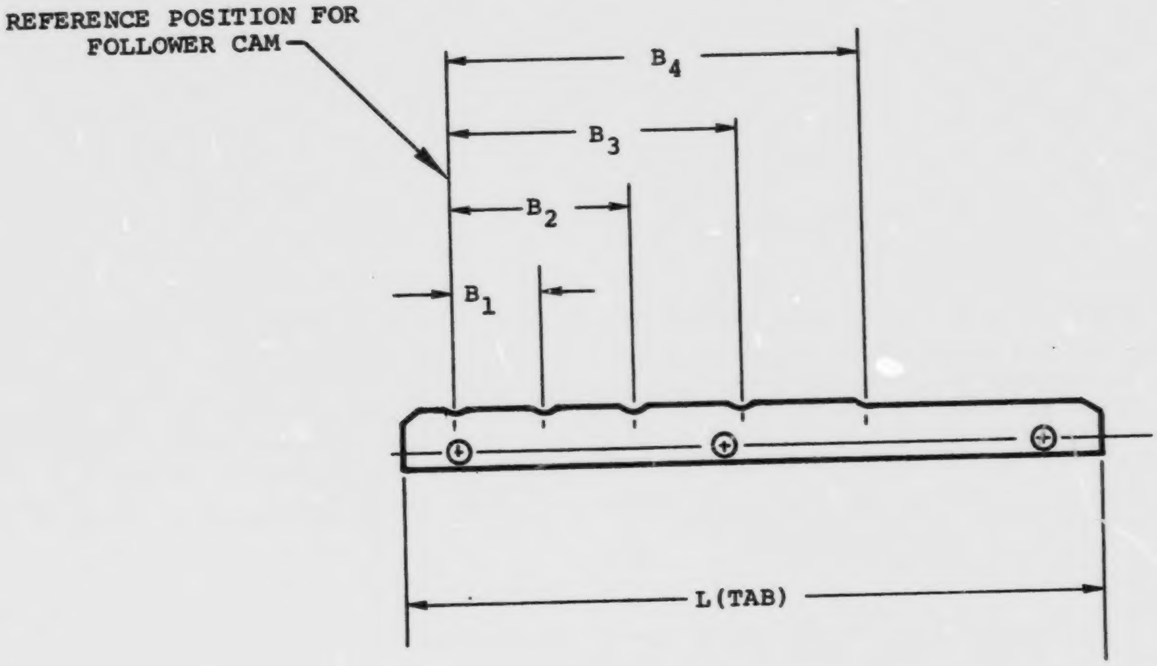
NOTES:

1. SAMPLING PROBE ASSEMBLY SKP26000 INSTALLED AT EXIT PLANE OF ENGINE TAILPIPE.
2. HORIZONTAL AND VERTICAL PROBE SETUP DIMENSIONS FOR EACH ENGINE SERIES TESTED ARE LISTED AS SHOWN AND ARE LOCATED FROM THE INSIDE DIAMETER OF THE OUTER TAILPIPE WALL. THIS INITIAL SETUP POSITION ALONG WITH USING THE APPROPRIATE PROBE CONTROL BAR SETUP ACCORDING TO FIGURE 16 WILL CENTER POSITION THE SAMPLING PROBE WITHIN EACH OF THE FIVE EQUAL ANNULUS AREAS THAT COMPRISE THE ENGINE TAILPIPE AREA.
3. DOTS REPRESENT FIVE POSSIBLE SAMPLING PROBE POSITIONS AT 3, 6, 9 and 12 O'CLOCK LOCATIONS FACING THE ENGINE TAILPIPE.

EMISSIONS SAMPLING PROBE SETUP DIMENSIONS
FOR EACH ENGINE TESTED

FIGURE 15

PART NO.	A	B_1	B_2	B_3	B_4	L
SKP26009-1	GTCP30	.27- .29	.59- .61	.99-1.01	1.60-1.62	5.97-6.03
-2	GTCP36	.33- .35	.73- .75	1.23-1.25	1.95-1.97	5.97-6.03
-3	GTCP85	.43- .45	.95- .97	1.59-1.61	2.51-2.53	5.97-6.03
-4	GTPR831	.49- .51	1.05-1.07	1.69-1.71	2.49-2.51	5.97-6.03
-5	GTCP165	.38- .40	.81- .83	1.29-1.31	1.85-1.87	5.97-6.03
-6	TSCP700	.96- .98	2.08-2.10	3.45-3.47	5.45-5.47	6.62-6.68
-7	GTCP660	1.00-1.02	2.16-2.18	3.60-3.62	5.69-5.71	6.62-6.68
-8	TSE231	.37- .39	.80- .82	1.28-1.30	1.84-1.86	5.97-6.03
-9	T76	.53- .55	1.15-1.17	1.91-1.93	3.01-3.03	5.97-6.03
-10	TFE731	.61- .63	1.32-1.34	2.20-2.22	3.47-3.49	5.97-6.03



EMISSIONS SAMPLING PROBE CONTROL BAR
SETUP DIMENSIONS REQUIRED TO DIVIDE ENGINE EXHAUST
AREA INTO FIVE EQUAL ANNULI

FIGURE 16

TABLE 5

MAXIMUM LOAD LIMITS FOR EXHAUST EMISSIONS MEASUREMENT TEST

Engine Model	Engine Rotor Speed Percent	Shaft Load shp	Bleed Air Extraction lb/min	Max Rated EGT, °F (Combination Shaft/Bleed)
		Auxiliary Power Units		
1. GTCP30-92	100	40	28.5	1320
2. GTCP36-6	100	160	68.5	1200
3. GTCP85-98 (-98D, -115)	100	160	128	1250
4. GTCP85-98CK	100	160	128	1150
5. GTCP85-129	100	160	110	1200
6. GTCP85-180 (sub for -98CK)	100	160	158	1200
7. GTC85-90 (-90B)	100	0	122	1175
8. GTCP660-4	100	300	275	1215
		0	515	
9. TSCP700-4	60 (Idle)	142	Max available (Limited by max EGT)	1005
LP-Spool Speed, N_1	80	142	↓	1005
	99	142		1005
	100	142		1005
		AIRCRAFT PROPULSION ENGINES (SEA LEVEL, STATIC, STANDARD DAY)		
10. TPE331-43A	65 (Idle)	No Load	--	
	100	575	--	1060
11. TPE331-151G	65 (Idle)	No Load	--	
	100	665	--	1060
12. TPE331-201A	65 (Idle)	No Load	--	1060
	100	715	--	1060
13. T76-G-410 (sub for -201A)	65 (Idle)	No Load	--	
	100	715	--	1060
14. TPE331-3U-303G	65 (Idle)	No Load	--	
	100	840	--	1060
				Maximum Inter-Turbine Temperature
15. TSE231-1	65 (Idle)	No Load	--	
	100	474	--	1404
		Maximum Thrust, lb		
16. TFE731-2	100	3500	--	1545

NOTES:

1. Engine tests were run at Phoenix (altitude ≈ 1092 ft) and at prevailing ambient temperature, pressure, and humidity.
2. Maximum shaft/bleed loads shown are not simultaneously possible when maximum EGT is limiting.
3. Shaft load limits shown does not necessarily reflect the maximum shaft load capability specified in the application rating.
4. See Table 6 for the corresponding engine power setting reference numbers that identify engine load condition.

TABLE 6

ENGINE POWER SETTING REFERENCE NUMBERS CORRESPONDING TO LOAD CONDITIONS

Shaft or Thrust Load shp or lb % Maximum (Table 5)	Shaft or Thrust Load Only	Bleed Air Extraction Only % Maximum Bleed			Combined Bleed/Shaft Load
		25	50	75	100% or Max Rated EGT, °F
0	1	2	3	4	5
25	6				10
50	11				15
75	16				19
100	20				22

ESTIMATED EXHAUST GAS TEMPERATURE LIMITS FOR EMISSIONS TEST

Power Setting Number	$(EGT)_{test}$ equals --
1	EGT specified for ground idle condition
2	Propulsion engines: EGT specified for flight idle Auxiliary power units: $(EGT)_{idle} + 1/4\ [(EGT)_{max} - (EGT)_{idle}]$
3	$(EGT)_{idle} + 1/2\ [(EGT)_{max} - (EGT)_{idle}]$
4	$(EGT)_{idle} + 3/4\ [(EGT)_{max} - (EGT)_{idle}]$
5	$(EGT)_{max}$ shown in Table 5

continuously monitored on strip chart pen recorders. Example strip chart recordings are included in Appendix E of this report. Also, at each test condition, pertinent engine performance data was recorded on data sheets similar to that shown in Figure 17. Figures 18, 19, and 20 show photographs of example test setups for three gas turbine engines. Appendix B contains the emissions performance data reduction printout which shows a tabulation of the engine performance data obtained for each engine at each power setting comprising the load run schedule for the emissions measurement tests. Also tabulated are measured emission concentration in ppm, calculated emission index, lb/1000 lb of fuel consumed, and the calculated emission formation rate in lb/hr for each power setting and constituent emission. The following section will describe how each emission performance parameter is calculated.

FORM P-766 -1

ENGINE MODEL ____________, S/N ________, DATE ____________ FUEL: ________

ENGINE LOAD LIMITS (TABLE): SHP ____________, EGT____________°F ENGINE: PRODUCTION

BAROMETER: ____________ IN. Hg A OVERHAUL

BEFORE RUNNING TEST, CALL 273-7511 FOR DEWPOINT:__________°F DEVELOPMENT

RELATIVE HUMITITY: ______%

DATA POINT																
SPEED, N_1, RPM																
COMPR INLET TEMP, °F																
FUEL FLOW, OBSERVED, LB/HR																
TORQUE, IN.-LB																
EGT, °F																
INLET VENTURI ΔP, IN. H_2O																
COMPR DISCH PRESS., IN. Hg																
BLEED CONDITIONS																
BLEED ORIFICE PRESSURE, IN. Hg																
BLEED ORIFICE TEMP, °F																
BLEED ORIFICE ΔP, IN. H_2O																

ORIFICE DIMENSION:

SPEED FACTOR:

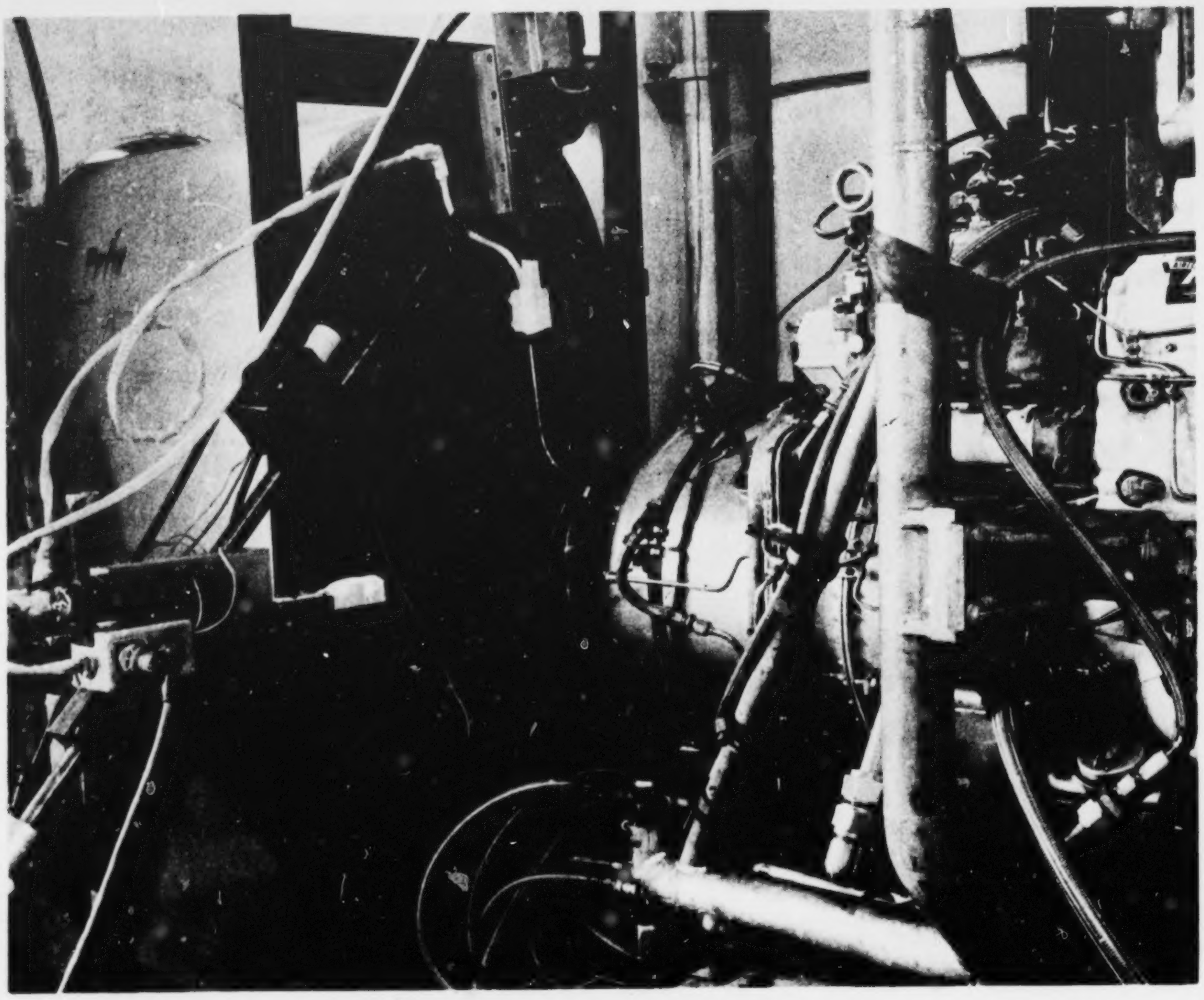
ROTAMETER NO.:

ALTITUDE EQUIPMENT DIVISION		
CALCULATED		
RECORDED		
DRAWN	WIS	5/7/71
CHECKED		
APPROVED		

EXHAUST GAS EMISSIONS DATA
APCO PROGRAM
FIGURE 17

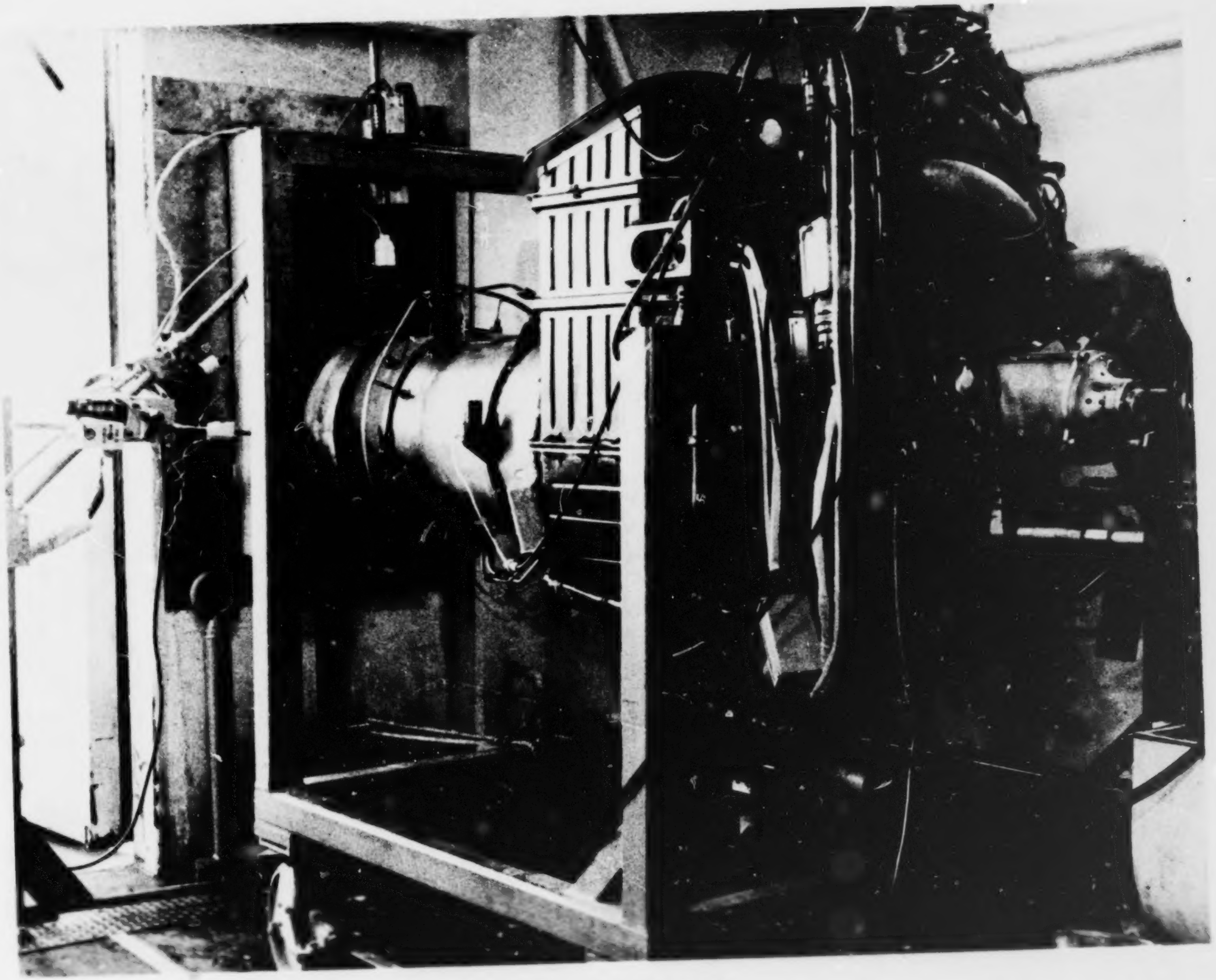
AiResearch Manufacturing Company of Arizona

B16156



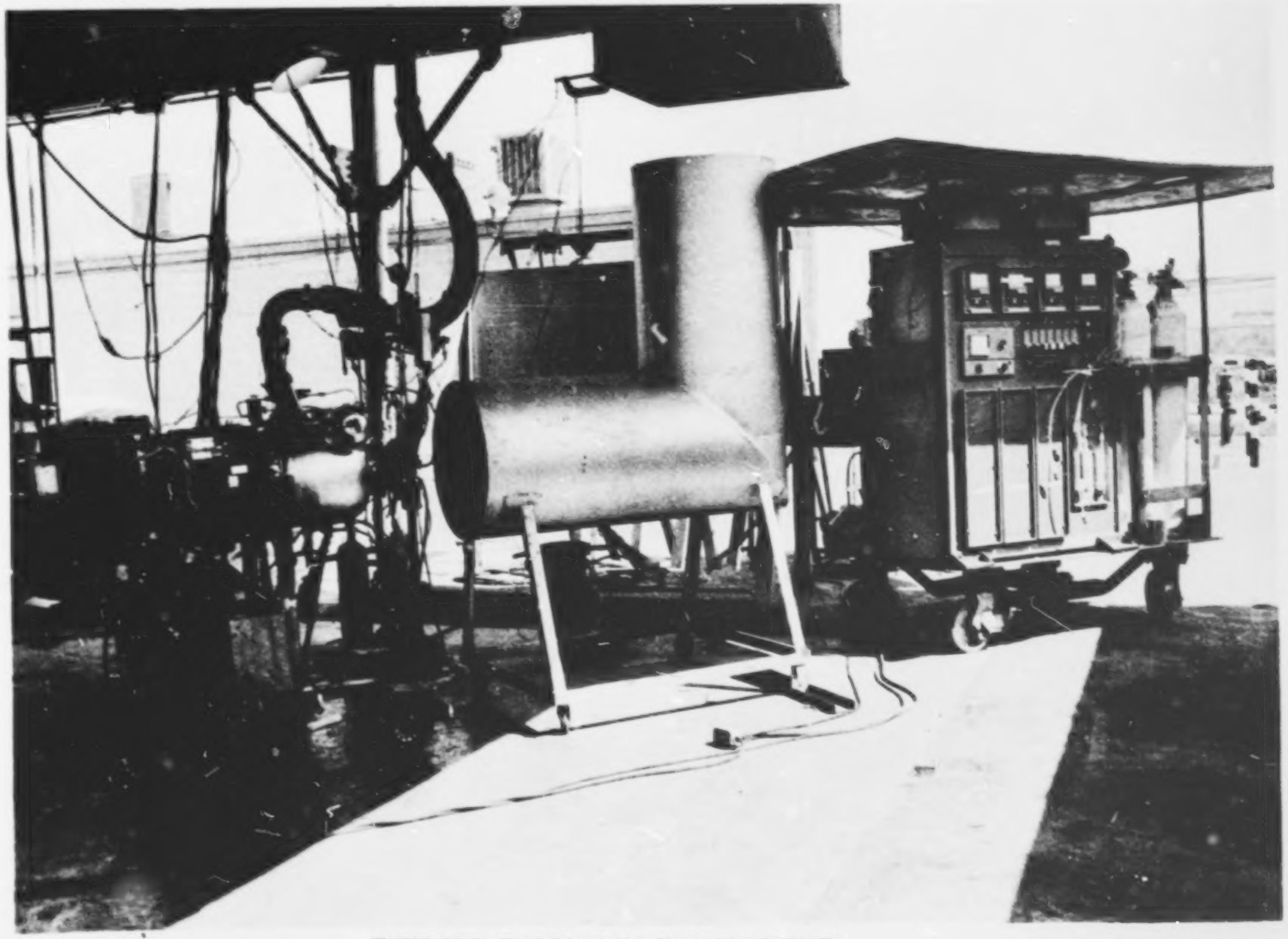
EMISSIONS SURVEY PROBE INSTALLATION
SETUP FOR TPE331 ENGINE

Figure 18



EXHAUST EMISSIONS MEASUREMENTS
TEST SETUP FOR GTCP660-4

Figure 19



EXHAUST EMISSIONS MEASUREMENT
TEST SETUP FOR GTC85-90B

Figure 20

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5.0 DISCUSSION OF TEST RESULTS

The preceding section described the test procedure and equipment used to collect and measure exhaust gaseous emissions on 32 commercial gas turbine engines. This section will begin by informing the reader of the various analytical criteria used to evaluate the following:

(a) Data reduction calculations

(b) Curve presentation of resultant emissions performance

(c) Sampling probe measurement techniques

After providing this background information emissions measurement test results will be discussed. Then, emission test results will be evaluated on the basis of an estimated engine duty cycle as determined for each aircraft engine application.

As was previously described, 10 emissions sample single-point movable probe readings were obtained for nearly all engines at each power setting. A mean value of the 10 readings was obtained and a maxi- mum deviation (T-sigma) from this mean was determined. A statistical distribution test was applied to the 10 sample readings to determine whether or not the sample fits a two-sided or "bell" distribution. If it did, probe readings were eliminated with the statistical assurance that 99 percent of the eliminated data was questionable. If a reading was eliminated by this test, a new mean value was determined from the remaining probe readings and the distribution test was reiterated. The concluding mean value of the probe readings are then used in all tabu- lar, including data reduction computer printout and curve plots presented in this report. The emissions performance data reduction printout and measured and calculated emissions performance plotted as a function of equivalent ratio are included in Appendices B and C respectively of this report. Other analytical criteria established for emissions performance in the data reduction calculations are as follows.

Fuel-Air Ratio

During planning phases of this program it became obvious that inlet air flow or exhaust gas flow measurement would be impractical.

A T76 propulsion engine was operated with an inlet flow measuring bellmouth and emissions data was recorded with the APCO equipment. Fuel-air ratios calculated with the use of emissions data were found to be within 5 percent of those determined from measured air and fuel flows. Accordingly, the use of fuel-air ratio as computed from exhaust emission measurement and fuel composition was recommended for the purpose of emissions programs in preference to fuel-air ratio determinations based on airflows obtained from measured or from estimated engine performance.

In the reduction of the data from the APCO equipment, the carbon monoxide and carbon dioxide recordings were considered as dry analysis data because of the use of a desiccant in the sampling train. The recordings of total hydrocarbons and oxides or nitrogen, however, include the water vapor initially in the air plus the water vapor formed by the combustion process. Accordingly, the concentrations of total hydrocarbons and oxides of nitrogen were corrected initially to dry conditions as follows:

$$S = \frac{S''}{1-v-w}$$

Where:

S - volumetric concentration of pollutant species (either CH_4, NO or NO_x) in dry exhaust gas

S" - volumetric concentration of pollutant species in wet exhaust gas containing water vapor in prevailing ambient air plus water vapor formed by combustion process

v - mole fraction of water vapor in exhaust from initial ambient conditions of air = $h \frac{M_e}{M_w}$

w - mole fraction of water vapor formed from combustion process

$$= \frac{R}{2} (a + b + d) - 2D$$

h - lb water vapor/lb dry air at engine inlet

M_e - molecular weight of exhaust products = 29.0 lb/ lb/-mole

M_w - molecular weight of water vapor = 18.02 lb/lb-mole

a - mole fraction of carbon dioxide in dry exhaust

b - mole fraction of carbon monoxide in dry exhaust

d - mole fraction of total hydrocarbons (expressed as CH_4) in dry exhaust. Use d" in Equation (1)

R - hydrogen/carbon ratio of atoms in fuel

For presentation of the test results on a volumetric basis, the most useful form of emission data appears to be in terms of percent (or ppm) by volume of wet exhaust gas from a combustion process with dry air. Accordingly, the dry volumetric concentrations of the emissions were corrected by the relationship:

$$S' = S(1-w)$$

Where S' - volumetric concentration of pollutant species in wet exhaust gas containing only the water vapor formed by the combustion process.

From the chemical equation of the combustion process, the fuel-air ratio can be determined from the expression:

$$f = \frac{(M_C + RM_H)}{M_A} \cdot \frac{(a + b + d)}{\left[1 + \frac{aR}{4} + \frac{b}{2} \cdot (\frac{R}{2} - 1) + d \cdot (\frac{R}{4} - 2) \right]} \qquad (3)$$

where terms not previously defined are:

f - fuel-air weight ratio, lb fuel/lb dry air

M_A - molecular weight of air = 28.9 lb/lb-mole

M_C - atomic weight of carbon - 12.01 lb/lb-atom

M_H - atomic weight of hydrogen = 1.008 lb/lb-atom

Emissions Index

An emission index expressed as pounds of pollutant per pound of fuel consumed was calculated from the equation

$$E_s = \frac{S'M_s}{(M_c + RM_H)\ (a' + b' + d')} \qquad (4)$$

where prime values indicate wet measurements and terms not previously defined are:

E_S - emission index, lb pollutant species, S/lb of fuel consumed

M_S - molecular weight of pollutant species S, lb/lb-mole

= 44.01 for CO_2

= 28.01 for CO

= 16.04 for CH_4

= 30.01 for NO

= 46.01 for NO_2

Note that the total oxides of nitrogen on an emission index basis could be computed as NO_2 only or the sum of $E_{NO} + E_{NO_2}$ where the volumetric concentration of NO_2 must be determined from the difference of the NO_x - NO readings. A comparison of total oxides of nitrogen were calculated by these two methods for the TPE731-2:

(a) Considering all oxides of nitrogen as NO_2

(b) Considering total oxide flow as the sum of NO flow and NO_2 flow

The difference in emission index and pollutant flow rate for the two methods is substantial as shown by Figure 21. At the peak thrust condition measured, the flow calculated using Method 1 is 49-percent higher than that calculated using Method 2. The first method is predicated upon the atmospheric conversion of NO to NO_2 within 3 to 5 hours from the time of combustion. For this program, at the request of OAP (APCO), all emissions were computed on the basis to total oxides of nitrogen expressed as NO_2.

Formation Rate

The formation rate of emissions for use in computing the total weight of emissions for a particular engine load cycle can be determined from

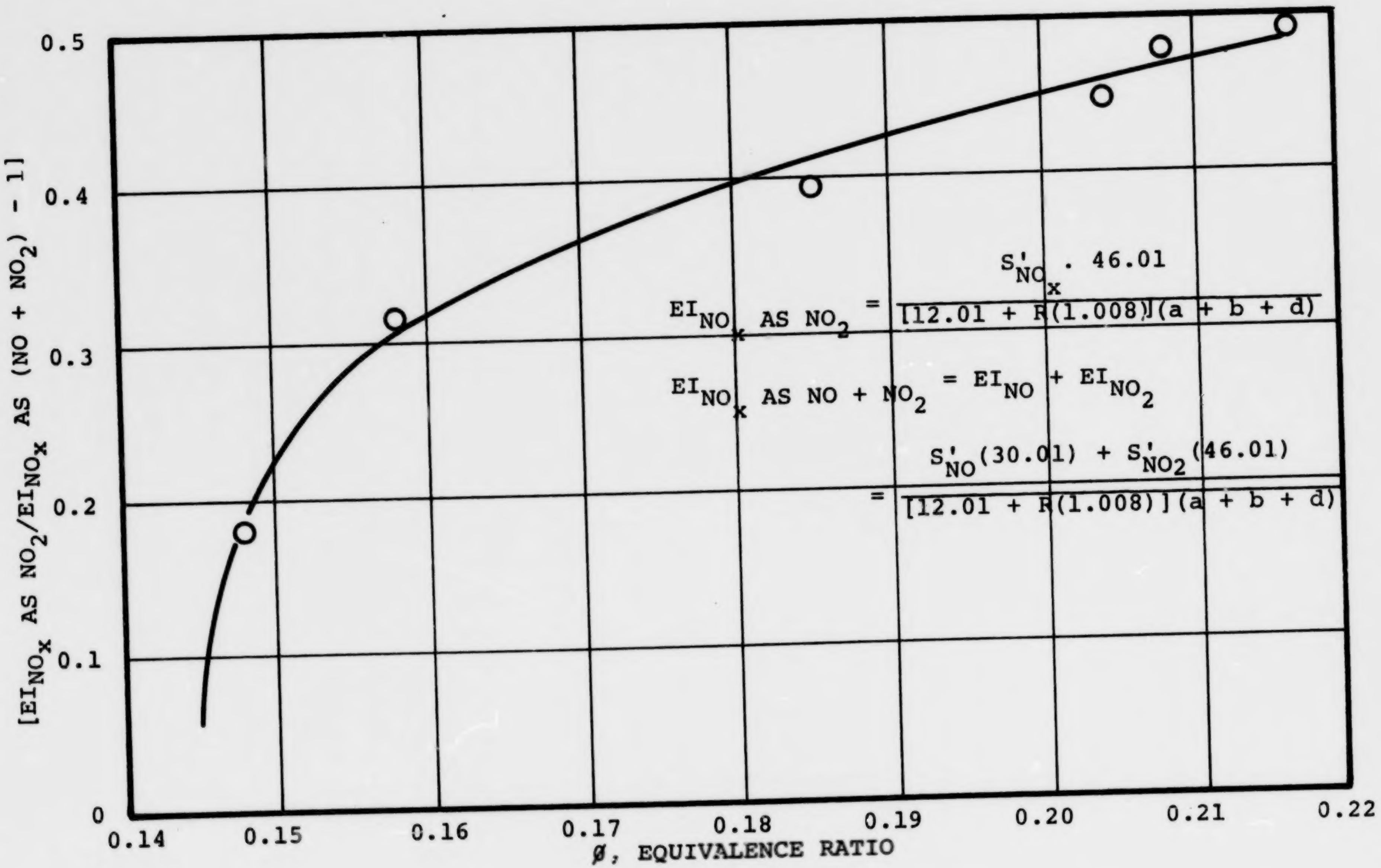
$$F_S = E_S \times W_f$$

Where F_S - formation rate of pollutant species S, lb/hr

W_f - engine fuel weight-flow rate, lb/hr

Volumetric concentration, emissions index, and emission formation rate for each engine tested together with the engine performance data are presented on test summary printout in Appendix B of this report.

Several methods were examined before selecting the most adequate method of plotting emissions performance data. Emissions data are known to vary as a function of such engine parameters as shaft load and bleed load, combustor parameters including combustor inlet airflow, pressure, temperature (including combustor discharge temperature referred to standard day conditions), fuel-air ratio and equivalence



$$EI_{NO_x} \text{ AS } NO_2 = \frac{S'_{NO_x} \cdot 46.01}{[12.01 + R(1.008)](a + b + d)}$$

$$EI_{NO_x} \text{ AS } NO + NO_2 = EI_{NO} + EI_{NO_2}$$

$$= \frac{S'_{NO}(30.01) + S'_{NO_2}(46.01)}{[12.01 + R(1.008)](a + b + d)}$$

RELATIONSHIP OF EMISSION INDEX FOR NO_x
AS NO_2 AND NO_x AS $NO+NO_2$ AS A
FUNCTION OF EQUIVALENCE RATIO
FOR THE TFE731-2 ENGINE TEST
FIGURE 21

ratio. Since shaft load and bleed load are not conveniently related as a single parameter for emissions plots, and since both loading methods affect combustor fuel-air ratio or equivalence ratio, the most suitable choice for data correlation appeared to be one of these combustor parameters. As a test for determining which parameter would better represent the independent variable or abscissa for emissions plots, two curves were plotted and compared with respect to data scatter using 85 Series engine data. The data used for comparison is shown on Pages 50 and 53 of Appendix C. It was concluded that the difference between data points observed in each plotted band or envelope of emissions were negligible regardless of the abscissa chosen.

Using equivalence ratio as the independent variable has the following advantages:

(a) Equivalence ratio is defined as the actual fuel-air ratio at the operating condition to the stoichiometric fuel-air ratio for the fuel used. Consequently, a direct comparison of emissions results may be made regardless of the fuel used.

(b) Both shaft and bleed-air extraction load engine performance data can appear on the same curve.

Therefore, all emissions performance data and pertinent engine performance data were plotted as a function of equivalence ratio and appear in Appendix C of this report. Also note that Appendix C data was broken down into engine groups in accordance with field service applications and as coincidently related to aircraft size. Accordingly,

Group 1 - Propulsion Engines - TPE331- TFE731, TSE231 and T76 Engine models

Group 2 - Small Auxiliary Power Units - GTCP30 and GTCP36 Engine Series used on-board small business/executive aircraft

Group 3 - Medium Size Auxiliary Power Units - GTCP85 Engine Series used on-board Boeing 727 and 737, BAC1-11 or DC-9 Aircraft

Group 4 - Large Auxiliary Power Units - GTCP660 and TSCP700 Engine Series used on-board Boeing 747 and DC-10 Aircraft

Furthermore, note that because of the large quantity of data accumulated, data points of individual engine tests are not shown connected. Engine groups were surrounded by envelopes or bands to identify possible trends in the data. If a group consisted of only one or two engines, the maximum data of the sample size tested was shown by a single line.

Emissions Sampling Probe Measurement Techniques

Of the three methods for obtaining exhaust gaseous emissions from gas turbine engines in use at the present time the single-point movable sampling probe technique as used in this test program is considered to be the most accurate. Unfortunately, it is also the most cumbersome to use. Improved accuracy over the sample readings taken by the single-point fixed probe and 12-point fixed probe as described earlier in the description of test Section 4. may be attributed to the aerodynamic cleanliness of the movable sampling probe design and the movable feature which permits sampling sometimes significant variations in emissions radial and circumferential to the engine tailpipe.

Table 7 presents 12-point movable (average of 3, 6, 9 and 12 o'clock positions) emissions measurements compared to the 12-point average fixed probe measurements for test conducted on GTC85-90B, a "bleed" engine, over a range of power settings. Although the emission measurement differences can be significant when the working range of the given gas analyzer instrument is small, no conclusions were determined because of the limited number of engines tested.

Further investigation was made regarding emissions results obtained from the movable probe assembly. Table 8 presents a comparison of a 6-point survey, 3 readings each, at the 12 and 3 o'clock position to a 12-point survey or 3 readings in each of the 12, 3, 6 and 9 o'clock positions covering the entire tailpipe. It was concluded that the majority of the data taken in this test program along the radii (5 readings each) leading to the 12 and 3 o'clock positions is a good representation of the data taken at all four radial locations.

A comparison of Tables 7 to 8 shows that the data obtained by the 6-point survey, at the 12 and 3 o'clock positions, more closely represents the 12-point survey, at the 12, 3, 6, and 9 o'clock positions, than the 12-point averaging probe.

TABLE 7

12-POINT MOVABLE VS 12-POINT FIXED SAMPLING PROBE COMPARISON TEST

	Emissions Measurement at the Power Setting Reference No. Shown				
Sampling Probe Used	1	2	3	4	5
			CO_2 Mole %		
Movable					
6-point survey, (12 & 3 o'clock)	1.49	1.97	2.44	3.02	3.50
6-point survey, (6 & 9 o'clock)	1.49	1.94	2.45	3.08	3.57
Average	1.49	1.955	2.445	3.05	3.535
Fixed	1.47	1.93	2.43	2.95	3.49
Difference	0.02	0.025	0.015	0.10	0.045
[1-(fixed/movable, avg)] 100, %	1.3	1.3	0.06	3.3	1.3
			CO, PPM		
Movable					
6-point survey, (12 & 3 o'clock)	387	470	507	452	399
6-point survey, (6 & 9 o'clock)	404	467	513	462	395
Average	395	468.5	510	457	397
Fixed	390	471	501	465	419
Difference	5.0	2.5	9.0	8.0	22.0
[1-(fixed/movable, avg)] 100, %	-1.25	-1	-1.8	1.8	5.5
			NO_x, PPM		
Movable					
6-point survey, (12 & 3 o'clock)	16.4	23.7	28.9	36.4	43.1
6-point survey, (6 & 9 o'clock)	17.9	23.0	29.4	36.4	43.1
Average	17.15	23.35	29.15	36.4	43.1
Fixed	16.5	22.3	28.0	35.0	40.0
Difference	0.65	0.05	1.15	1.4	3.1
[1-(fixed/movable, avg)] 100, %	±3.3	5	4.3	4.0	7.75
			NO, PPM		
Movable					
6-point survey, (12 & 3 o'clock)	8.3	12.6	17.1	35.9	33.7
6-point survey, (6 & 9 o'clock)	13.5	17.6	25.1	33.9	39.5
Average	10.9	15.1	21.1	34.9	36.6
Fixed	10.5	17.5	18.0	25.0	31.0
Difference	0.4	2.4	3.1	9.9	4.6
[1-(fixed/movable, avg)] 100, %	4.0	-13.7	17.2	40.0	16.2
			HC (Hot), PPM (Propane)		
Movable					
6-point survey, (12 & 3 o'clock)	7.5	3.7	1.5	0.2	0.15
6-point survey, (6 & 9 o'clock)	0.9	5.1	2.8	0.6	0.26
Average	4.2	4.4	2.15	0.4	0.205
Fixed	1.0	0.6	4.2	1.8	1.85
Difference	3.2	3.8	2.0	1.4	1.6
[1-(fixed/movable, avg)] 100, %	Not a representative test range, ppm too low for comparison				

NOTES:
1. Probe comparison test conducted on GTC85-90B, S/N P-24376, June 16, 1971
2. Power setting number definitions 1 through 5 shown in Table 6.
3. Fixed probe comprised of 12 gas sample collection points manifolded to a single sample line.

TABLE 8

COMPARISON OF 6-POINT SURVEY (12 AND 3 O'CLOCK) TO 12-POINT SURVEY AVERAGE, USING MOVABLE SAMPLING PROBES

	Emissions Measurement at the Power Setting Reference No. Shown				
Sampling Probe Used	1	2	3	4	5
Movable			CO_2 Mole %		
6-point survey, (12 & 3 o'clock)	1.49	1.97	2.44	3.02	3.50
6-point survey, (6 & 9 o'clock)	1.49	1.94	2.45	3.08	3.57
12-point average	1.49	1.955	2.445	3.05	3.535
Difference	0	0.015	0.005	0.003	0.035
[1-(6 pt/12 pt average)] 100, %	0	0.8	0.2	0.1	1.0
Movable			CO, PPM		
6-point survey, (12 & 3 o'clock)	387	470	507	452	399
6-point survey, (6 & 9 o'clock)	404	467	513	462	395
12-point average	395	468.5	510	457	397
Difference	9.0	1.5	3.0	5.0	2.0
[1-(6 pt/12 pt average)] 100, %	2.3	0.3	0.6	1.1	0.5
Movable			NO_x, PPM		
6-point survey, (12 & 3 o'clock)	16.4	23.7	28.9	36.4	43.1
6-point survey, (6 & 9 o'clock)	17.9	23.0	29.4	36.4	43.1
12-point average	17.15	23.35	29.15	36.4	43.1
Difference	0.75	0.35	0.25	0	0
[1-(6 pt/12 pt average)] 100, %	4.4	1.5	0.9	0	0
Movable			NO, PPM		
6-point survey, (12 & 3 o'clock)	8.3	12.6	17.1	35.9	33.7
6-point survey, (6 & 9 o'clock)	13.5	17.6	25.1	33.9	39.5
12-point average	10.9	15.1	21.1	34.9	36.6
Difference	2.6	2.5	4.0	1.0	2.9
[1-(6 pt/12 pt average)] 100, %	2.4	1.7	1.9	0.3	8.0
Movable			HC (Hot), PPM (Propane)		
6-point survey, (12 & 3 o'clock)	7.5	3.7	1.5	0.2	0.15
6-point survey, (6 & 9 o'clock)	0.9	5.1	2.8	0.6	0.26
12-point average	4.2	4.4	2.15	0.4	0.205
Difference	3.3	0.7	0.65	0.2	0.055
[1-(6 pt/12 pt average)] 100, %	78.5	16.0	30.2	50.0	26.8

NOTES:

1. Probe comparison test conducted on GTC85-90B, S/N P-24376, June 16, 1971
2. Power setting number definitions 1 through 5 shown in Table 6

With these facts in mind a brief review of the significant features to the emissions stratification data presented in Appendix D will be made. For example:

(a) GTCP85-180, S/N P-567 - CO_2, NO, and NO_x readings for bleed air test conditions at probe No. 1 are grouped lower than other probe readings. (Note that probe numbers or locations are identified in Figure 8.) This possibly represents an example of ambient-air recirculation at probe location No. 1 with correspondingly lower readings expected for CO and HC(Hot).

(b) Radial emissions stratification is shown by probe locations 1 to 5 or 6 to 10; circumferential stratification is shown by comparing probes locations 1 to 5 with probe locations 6 to 10.

(c) In order for a 12-point fixed probe such as shown in Figure 9 to represent single-point movable probe data plotted in these curves, the fixed probe at locations 1, 3, 5, on the curves must be representative of data obtained by the movable probe at locations 1, 2, 3, 4, 5; probe locations 6, 8, 10, must be representative of data obtained at probe locations 6, 7, 8, 9, 10, and so on.

(d) Examples of data showing a significant lack of agreement with the criteria of statement (c) above are itemized below:

Engine	S/N	Test No.	Emission	Figure No.
GTCP36-6	P-34772	5, 10	CO	5-81
GTCP85-98	P-15454	5, 22	CO	5-126
GTCP85-98	P-15257	5, 10, 15, 19, 22	CO	5-131
GTCP85-115	P-18725	10, 22	CO	5-141

(e) Examples of data with significant stratification in the circumferential location change of 3 o'clock to 12 o'clock are itemized below:

Engine	S/N	Test No.	Emission	Figure No.
TPE331-1-151G	P-91165	1	HCH	5-47
TPE331-1-151G	P-91168	1	HCH	5-53
TPE331-43A	P-61157	1	CO, HCH	5-56/57
GTCP30-92 (Atomizers)	P-28794	5,10,15, 19,22	CO, NO, NO_x	5-66/68/69
GTCP660-4	P-37596/ 37705	All	HCH, NO_x	5-177/179
TSCP700-4	P-90122/ 90123	All	CO_2, HCH NO_x	5-186/187/ 188

(f) Emissions symbols plotted as zero ppm represent probe location data eliminated from the samples by means of the "Student's T" distribution test previously discussed in this section or probe locations that were intentionally omitted.

(g) On two GTC85-90/90B engines, S/N P-5786 and P-24376, 20 probe locations as defined in Figure 8 are plotted instead of ten.

It is realized that the gas turbine industry does have a need for a standardized emissions measurement technique and a need for knowledge regarding the reliability of data obtained for each technique studied.

Evaluation of Test Results

Emissions performance test results with respect to measured levels of constituent emissions for each engine, from one engine to another, and for extremes of power setting may best be discussed by reviewing the tabular summary of Appendices B and C shown in Tables 1 and 2. These tables are shown in the Summary Section 2. Also, observe Figures 1, 2, 3, and 4 in the Summary. Each figure shows the basic trends in emission performance exhibited by each engine series tested on the basis of emission index plotted as a function of equivalence ratio and how they compare to one another. These curves reflect essentially the same trends observed for measured levels of emissions concentration about to be discussed. Table 1 presents the extremes observed for measured emission concentrations in parts per million, ppm, for each engine series tested over the complete operating load range. Also, the number of engines tested is included to reflect the fact that as the number of engines tested in a given series increases so does the measured minimum to maximum emissions levels.

The GTCP30-92 engine tests using a vaporizer combustion system were not included in the table so as not to influence the 30 Series engines comparative value to other engines in the table. The 30 and 85 Series engines produced highest CO_2 emissions; the 731, 331, and 85 Series engines produced highest CO emissions; the 331 Series engine produced highest hydrocarbon emissions, and the 731, 231, 331, and 700 Series engines produced highest NO - NO_x emissions. However, it must be realized that this is not necessarily representative of the relative emissions standing of the engine series when the engines are operated under the weighted duty cycles discussed in subsequent paragraphs.

Table 2 gives a relative comparison of these engines at idle and full load operating conditions. For the idle operation correlation the propulsion engine data is presented for the increased flight idle speed to compare to APU idle operation at 100 percent speed. The

700 APU at 100 percent speed is always loaded. Therefore, a value of 91 percent speed (standby operation) with no shaft loading was chosen for the comparison. Full load for propulsion engines is represented by test power setting 20 and for APU's by power setting 15 as defined in Table 6. This table essentially defines the envelope maximums and minimums for all AiResearch product lines tested at a minimum load condition (flight idle) and a maximum load condition (maximum exhaust gas temperature in typical application).

The trends in the propulsion engine group show the effects of three different engine configurations. These configurations are: first, a fixed shaft speed TPE; second, a variable speed two-spool TFE731 engine; and third a gas generator free-turbine 231. All three engine configurations operated over the cycle-pressure ratio range of 2.5 to 6.0, but showed different slopes of emission versus equivalence ratio. The difference in slopes is attributed to the fact that the variable speed engines can to a large extent, adjust combustor airflow to meet loading changes or fuel flow changes. In contrast, the fixed shaft speed engines are relatively inflexible with respect to adjustment of airflow. A large change in loading or fuel flow results in but a small change in airflow for these engines. The result is a narrower equivalence ratio band for variable speed engines.

This trend is also obvious if the fixed shaft TPE is raised in speed from the ground idle or 65 percent maximum speed to the governed, flight idle, 100 percent speed. The slope that would result by connecting the two idle data points would be very steep and cover a narrow equivalence ratio. Although the fuel-air ratio effect discussed here is noticeable, it should be noted that other parameters such as combustor inlet pressure, temperature rise, mixing, etc., are also involved to a lesser degree.

Comparison of the 36 Series engine emissions with 30 Series emissions reveals that the can-type combustor of the 30 Series yield a lower level of emissions than the 36 Series of the same basic size. The difference could be attributed to the small sample size or the combustor design but would require further investigation before any degree of certainty could be applied.

Vaporizing and atomizing type combustors were tested on a 30 Series engine. However, the sample size tested was again too small to draw definite conclusions in view of the data scatter observed in other engine tests. However, on the basis of a single comparative test, the vaporizer emitted less hydrocarbons and more oxides of nitrogen than the atomizing combustor. Carbon monoxide emissions were lower for the vaporizing combustor on the low load only.

A sample group of three GTC85-90/90B (bleed-air extraction only) engines were singled out of the 85 Series family because of their inherently higher CO emission level. This engine has a smaller combustor than any other 85 Series engine which probably accounts indirectly for the high CO emission by a mixing geometry influence on the combustion process. Other emissions for the GTC85-90/90B were within the envelopes defined by other 85 Series engines.

In the case of the fifteen combination load-type 85 Series engines, it was of interest to note that the GTCP85-98, S/N P-15541, appeared at the top of the 85 Series hydrocarbon envelope, while the GTCP85-98, S/N P-11527, of the same series type, appeared near the bottom of this envelope. At the high equivalence ratios, this comparison of two engines indicated hydrocarbon content ranging from 1.0 ppm to 100 ppm (see Appendix C, page 44).

The data spread observed in comparing these 85 Series engines can most likely be attributed to the wide variety of combustor designs used in the 85 Series engines; however, the hydrocarbons comparison above is a good example of the emissions distribution difference from one engine sample to another. In general, the following hardware differences exist in this engine group.

(a) The GTCP85-98, -98D, -115, and -129 engine models use the same radial-flow compressors, atomizers, and turbine wheels, but different flame tubes and turbine nozzles.

(b) The GTCP85-98CK and -180 engine models use the same radial-flow compressors, flame tubes, atomizers, and turbine wheels, but use different turbine nozzles.

The 660 engines showed a CO emission curve that was almost flat with increasing load. This characteristic would have to be studied further before an explanation could be presented; however, the straight-through flow annular combustor is a design configuration not used in engines other than the 660 Series and may be partially responsible for the flat CO characteristic. This engine also has a high compressor surge bleed on low loads which requires higher turbine temperatures during a low through flow condition. Operation under this surge bleed condition contributes to the flat CO characteristic by producing CO at idle more comparable to CO at high loads. Surge bleed air from the compressor is dumped into the turbine exhaust and contributes somewhat to the HC reading instabilities at low loads.

Engines in the 700-4 group also have variable speed capabilities, steep slope emissions curves, and the narrow equivalence ratio band indicated by the 731/231 propulsion engines. Emission levels were also more comparable to the propulsion engines group rather than the other APU groups.

If a comparison between annular and can-type combustors is desired, an overlay of Group 1 or Group 4 curves (which show the effects of using existing annular burner configurations) upon Group 2 or Group 3 curves, (which show the results of engines using existing can-type burner configurations) can be made. With high loading or high equivalence ratios, the annular burner configurations give a lower CO and HCH emission level, but higher NO_x emission levels. These differences in emission levels could logically be attributed to the higher combustion temperatures employed in annular burner designs and geometric differences between the two types of burners, atomizers and mixing methods. However, investigation of atomizing and mixing geometries could provide considerable areas for future work and would result in a better understanding of these differences.

All engines produced higher levels of NO_2 emissions than were suspected from other industry surveys. Highest levels of NO_2 occurred at idle and highest levels of total oxides of nitrogen appeared at full load conditions. Previous survey work had largely been centered on the use of NDIR instruments for measuring NO only. Nitrogen dioxide readings in this program frequently comprised one-fourth to three-fourths of the total oxides of nitrogen emitted from these engines at idle. A check of several test power settings using a NDUV (non-dispersive, ultra-violet) analyzer on an 85 Series engine at the Bureau of Mines in Bartlesville, Oklahoma, confirmed the magnitude of NO_2 readings received on the chemiluminescent analyzer.

The effect of water in the exhaust gas on the reading level of the chemiluminescent analyzer was also considered. An ice bath condenser was built into the sampling system just before the analyzer with a by-pass for sample flow either through or around the condenser. Dry ice was used to assure adequate condenser temperature differentials. Wet and dry NO - NO_x readings are tabulated below for the GTCP85-180, S/N P-593 for probe location 3.

Emission	NO_x		NO	
Power Setting	dry	wet	dry	wet
1 (idle)	21.0	21.0	13.6	13.0
22 (full load)	61.0	57.0	50.0	47.0
span gas	49.5	49.5		

For the temperature, humidity, conditions of test, and fuel composition used, the calculated wet and dry differences at full load were comparable to the measured values.

Background or ambient hydrocarbon levels were measured in an enclosed test cell with engines non-operative and at various load conditions. Readings of 3.0 to 3.5 ppm were considered as average for enclosed facilities. Two engines tested in open air facilities were the GTC85-90B, S/N 24504 and the GTC85-90B, S/N 24376 where the background level was not noticeable.

A brief discussion of the gas analyzer instrumentation used for this test program, the supply of various gases necessary to serve as a standard for the gas analyzer instrument calibration, and gas analyzer instrument performance during the test will appear in the following paragraphs. Data on hydrocarbon emissions was collected using two analyzers, the Beckman models 402 heated analyzer and 108A cold hydrocarbon analyzer. This report presents data entirely resulting from the heated HC analyzer which is generally accepted as the preferred method since condensed hydrocarbons in the sampling lines and equipment is less likely to occur. A flame ionization detection method is used in both analyzers. The model 402 analyzer had built in controls for maintaining a 10 feet long sample line above 300°F.

Oxides of nitrogen were measured using a Thermo Electron Corporation (TECO) instrument model 10A capable of NO and NO + NO_2 measurements, the latter commonly referred to as NO_x. A thermal converter changes the NO_2 in the exhaust sample to NO since the analyzer is capable of measuring only NO.

Carbon monoxide and carbon dioxide were both measured on non-dispersive infra-red (NDIR) analyzers, Beckman model IR315L.

Hydrocarbon and chemiluminescent analyzer readings measured emissions on the basis of total wet exhaust products concentrations. Carbon monoxide and carbon dioxide measurements were taken after a desiccant removed water vapor from the sample. The heated 10 feet long stainless steel sample line was connected to the heated hydrocarbon analyzer where the sample was then divided into cold lines about 6 feet long for the chemiluminescent, NDIR, and cold hydrocarbon analyzers.

Gases are required for each analyzer to provide a method of instrument calibration. Calibration gases are used to set the zero and span (upscale) adjustment points of the electronic systems and recorders. In addition to calibration gases, a fuel and air supply are needed for the hydrocarbon analyzer burners and oxygen is needed for the chemiluminescent ozonator. The gases and their concentration levels used for this test are tabulated below.

Hydrocarbon Analyzers - Beckman Models 402 and 108A

Zero Gas - Purified Air, Hydrocarbon-free grade less than 0.1 PPM CH_4

Span Gas - Propane, 4.8 and 48.8 PPM concentrations, Balance - Air, By Scott Research Laboratories

Fuel Gas - 40 percent H_2/60 percent He mixture

Burner Air - Same as zero gas

CO/CO_2 NDIR Analyzers - Beckman Model IR315L

Zero Gas - Nitrogen

Span Gas - CO - 508 PPM

CO_2 - 2.12 percent

By Scott Research Laboratories

NO-NO_x Chemiluminescent Analyzer - Thermo Electron Corporation
Model 10A

Zero Gas - None, zero by turning sample flow off

Span Gas - NO - 53.2 PPM

NO_x - 11.2 and 50 PPM

By Scott Research Laboratories

Ozone Generator - O_2, commercial grade

Performance of all analyzers used in this program can be judged as very good. No attempt was made to correlate the validity of all instrument readings with other instrumental or chemical means for determining emission concentrations; however, all instruments were operated in accordance with manufacturer's recommendations and within specification temperatures.

Analyzers of the NDIR type were trouble-free during the entire test period. The heated FID analyzer burner ignitor circuit was troublesome in that a frequent transistor failure in the burner ignition circuit would render the instrument inoperative. The instrument was otherwise faultless, and reliable operation was possible by using a butane cigarette lighter to ignite the burner.

The chemiluminescent analyzer performed well except for the equipment required to maintain a vacuum in the reaction chamber. Vacuum system leaks caused considerable downtime, although usage of glyptal (red enamel) on plumbing joints external to the analyzer unit provided an excellent means of locating and repairing vacuum system leaks. Vacuum pump pipe threads were sealed with a combination of teflon tape and glyptal.

During testing, the operator of the chemiluminescent and heated FID analyzers determined the pace for data accumulation. At any specific power setting the ability to move from one probe location to another was paced by the chemiluminescent analyzer, which had to take two readings, NO and NO_x. A three-way solenoid on the thermal converter plumbing could have reduced measurement time for the 6000 NO - NO_x readings taken in this program. During engine power setting changes the pace was set by the restabilization time required for the heated FID instrument and sample line at the new hydrocarbon emission level. Samples of transient recording charts are provided in Appendix E for review.

Amplifiers for the analyzers were judged somewhat sensitive to ambient temperature. During this program Phoenix ambient temperatures rose from about 70°F to 110°F. Direct sunlight on the chemiluminiescent amplifier created instabilities during ambient temperatures of about 95°F (in the shade), and shade provided amplifier stability to about 100°F. All instruments were kept below these temperatures by blowing cool air from an evaporative water cooler over them.

Bottled calibration gases had to be turned off after each engine test; however, there were instances when their valves were inadvertently left open. Most analyzers had a selector valve in the gas lines helping to prevent excess loss of gases, by having most gases turned off during instrument operation. The heated hydrocarbon analyzer had a solenoid valve which closed off the burner fuel supply but not the high purity burner air. This design provided no backup valve to the air bottle and permitted the bottle to drain even when the instrument was not operating.

The quality of one air bottle appeared questionable in one operating environment. The purity of the air was specified to be less than 0.1 ppm hydrocarbons and yet an engine operating at maximum load measured a negative 0.7 ppm on the heated hydrocarbon analyzer. Subsequent zero checks on the instrument repeatedly showed good instrument calibration. Similar power settings on other engines showed values of about 0.3 ppm hydrocarbon and this engine confirmed the 0.3 value later in the test. Direct sunlight on the air bottle on a 110°F ambient day was believed to be responsible for vaporizing condensed hydrocarbons in the bottle, causing the zero gas to increase its readout level.

Gas Turbine Engine Duty Cycle Determination

Gas turbine engine duty or service cycles vary from one aircraft application to another. For example, for auxiliary power unit operation, some operators start the APU as soon as the aircraft touches ground while others prefer to use the APU only when the main engines are inoperative during the "park" mode. The FAA certification category imposed on an engine add still other differences to a given engine duty cycle. For example, auxiliary power units on-board Boeing 747 and McDonnell-Douglas DC-10 aircraft were FAA certified under the "essential power" category whereby APU operation is permitted for climb-out, inflight and descent modes of aircraft operations.

Testimony to on-board APU engine operation differences or duty cycle differences between commercial airlines applications are shown in Tables 9, 10, and 11. Each table represents the response to a duty cycle questionnaire sent to several major AiResearch APU and propulsion engine customers. Although Customer C did not report detailed duty cycle information with respect to the aircraft service cycle, various APU operational times were reported as follows:

	Engine Model		
	GTCP85-98 and -98CK	GTCP85-115	GTCP660-4
Application	Boeing 727, -100	BAC 1-11, 400/500	Boeing 747
APU Hours/Duty Cycle, Avg	1.4	2.0	2.0
APU Hours/Flight Hour, Avg.	1.3 Est.	2.1 Est.	1.0 Est.
APU Hours/Year	347,000	100,800	43,000

TABLE 9

TYPICAL DUTY CYCLES FOR AUXILIARY POWER UNITS (APU) ON-BOARD CUSTOMER A COMMERCIAL AIRCRAFT

Aircraft Service Cycle		AiResearch Engine Models											
Operating Mode	Description	GTCP85-98			GTCP85-98CK			GTCP85-129			GTCP660-4		
		A	B	C	A	B	C	A	B	C	A	B	C
Descent	Airplane approach to Airport	Not operated in flight			Not operated in flight			50%	7 kw 20 amp	15 min.	Not operated in flight		
Taxi	Light-off of APU after termination of main engine thrust reversal and taxi to ramp	50%	10 kw (30 amp)	5 min.	50%	10 kw (30 amp)	5 min.	50%	7 kw (20 amp)	5 min.	50%	32 kw (90 amp)	5 min.
Park	Airplane serviced, cleaned, refueled, and passengers boarded	500°F	18 kw (50 amp)	80 min.	500°F	18 kw (50 amp)	107 min.	MAX EGT	22 kw (60 amp)	40 min.	80%	54 kw (150 amp)	280 min.
Taxi	Taxi to end of runway	50%	10 kw (30 amp)	5 min.	50%	10 kw (30 amp)	5 min.	50%	7 kw (20 amp)	5 min.	50%	32 kw (90 amp)	5 min.
Climb	Climb to cruise Altitude	Not Operated in Flight			Not Operated in Flight			MAX. EGT	7 kw (20 amp)	15 min.	Not Operated in Flight		
Application		Boeing 727-100			Boeing 727-100/200			Boeing 737			Boeing 747		
APU Time/Duty Cycle, Average		90 Minutes			117 Minutes			80 Minutes			290 Minutes		
APU Hours/Flight Hour, Average		1.0			1.4			1.7			1.0		
APU Hours/Year		330,000			91,000			220,000			20,000		
Number APU'S Installed		150			28			73			9		
Hours/Year per APU, Average		2,200			3,250			3,300			2,220		

OPERATING LOAD CONDITIONS:

A = Bleed-Air extraction load operating point, percent of bleed airflow or operating EGT, °F

B = Shaft load operating point, SHP or kw

C = Engine run time for aircraft operating mode, min.

TABLE 10

TYPICAL DUTY CYCLES FOR AUXILIARY POWER UNITS (APU) ON-BOARD CUSTOMER B COMMERCIAL AIRCRAFT

Aircraft Service Cycle		AiResearch Engine Models											
		GTCP85-98			GTCP85-98CK			GTCP85-98D/W			GTCP660-4		
Operating Mode	Description	A	B	C	A	B	C	A	B	C	A	B	C
Descent	Airplane approach to airport	Not Operated in Flight			Not Operated in Flight			Not Operated in Flight			Not Operated in Flight		
Taxi	Light-off of APU after termination of main engine thrust reversal and taxi to ramp	0	0	4 min	0	0	3 min	0	0	3 min	0	0	6 min
Park	Airplane serviced, cleaned, refueled, and passengers boarded	80%	50 kw	33 min	80%	50 kw	34 min	90%	40 kw	32 min	80%	135 kw	135 min
Taxi	Taxi to end of runway	0	0	1 min	0	0	1 min	0	0	1 min	0	0	2 min
Climb	Climb to cruise altitude	Not Operated in Flight			Not Operated in Flight			Not Operated in Flight			Not Operated in Flight		
Application		Boeing 727-100			Boeing 727			DC-9			Boeing 747		
APU Time/Duty Cycle, Average		33 min			34 min			32 min			143 min		
APU Hours/Flight Hour, Average		1.2/1			1.2/1			1.75/1			0.8/1		
APU Hour/Year		105,080			99,216			66,680			42,232		

OPERATING LOAD CONDITIONS:

A = Bleed-air extraction load operating point, percent of bleed airflow or operating EGT, °F

B = Shaft load operating point, SHP or kw

C = Engine run time for aircraft operating mode, min

TABLE 11

TYPICAL DUTY CYCLES FOR TURBOPROP TPE331 AIRCRAFT PROPULSION ENGINES AS SUBMITTED BY LIGHT TWIN ENGINE AIRPLANE CUSTOMERS D AND E

Aircraft Service Cycle		AiResearch Engine Models					
Operating Mode	Description	Percent of Rated Power	TPE331-201A or T76 Time in Mode, min	TPE331-151G Time in Mode, min	TPE331-43A Time in Mode, min	Average Mode Time, min	"Weighted" Mode Time*, min
Ground idle	Engine startup and taxi to end of runway	15	8	8	3	5.5	5
Run-up	Check out at end of runway	50	0	0	0	0	2
Initial climb	Take-off and climb to 3000 feet	100	5	5	2	3.5	3
Final climb	Climb to cruise altitude (over 3000 feet)	100	5	5	10	7.5	7
Cruise	(Not pertinent to pollution near airport)	90	40	40	17	28.5	30
Descent	Descent to landing pattern altitude of 3000 feet	30	10	10	10	10	10
Cruise pattern	Hold in landing pattern at 3000 feet	50	2	2	1	1.5	2
Final approach	Descend and land	30	5	5	1	3	2
Ground idle	Taxi back to hanger	15	5	5	1	3	2
Application			Skyvan	CASA (212)	NAR Aero Commander		
Engine Hours/Duty Cycle, Average			1.33	--	0.67	Service Cycle Total Time = 63 min	
Engine Hours/Year, Average			1200	--	--		

*Mode time as recommended by AiResearch Flight Operations Department.

Because of the limited response to the duty cycle questionnaire, assistance from the AiResearch Flight Operations Department together with the information received on revised duty cycle for APU's and propulsion engines were determined. Tables 11 and 12 reflect this representative average or "weighted" duty cycle thought best representing the majority of engine customers. Subsequent emissions performance relating to engine duty cycles are based on these data. It is realized that total emissions generated by any product line is based on an estimated number of the duty cycles performed by the number of delivered engines at a given time. Tables 3 and 13 summarize these data.

In order to calculate the exhaust emissions formation rate for each APU "weighted" or estimated duty cycle two simplifying assumptions must be made: (1) As observed in the emissions performance plots in Appendix C, the resultant emissions are relatively insensitive or do not vary greatly with changes in combined bleed/shaft load ratio while operating at maximum rated exhaust gas temperature. Therefore, power setting 15, as described in Table 6, was chosen to represent a fully loaded APU. This power setting presents a bleed/shaft load ratio very nearly the same as was reported by customer B as shown in Table 10 for "park" mode of operation and (2) since aircraft taxi time represents only a small portion of the overall duty cycle time, exhaust emissions during the taxi mode will be approximated by adding the taxi mode time to the park mode time for evaluation at the park mode emissions levels.

By using the estimated duty cycle times shown in Table 12 and these simplifying assumptions, the average exhaust emission formation rates were calculated and are shown in Table 13.

Because emission formation rates are dependent upon fuel flow, they are a function of engine size or power. Therefore, a statistical

TABLE 12

SUMMARY OF ESTIMATED APU DUTY CYCLE TIMES WITH RESPECT TO COMMERCIAL AIRCRAFT SERVICE CYCLE

Aircraft Service Cycle		Approximate APU Time in Mode, min			
Operating Mode	Description	APU Load Condition	Small	APU Size Medium	Large
Descent	Airplane approach to airport	Not operated in flight	--	--	--
Taxi	Light-off of APU after termination of main engine thrust reversal and taxi to ramp	Max rated bleed/shaft	5	5	5
Park	Airplane serviced, cleaned, refueled, and passengers boarded	Max rated bleed/shaft	30	70	170
Taxi	Taxi to end of runway	Max rated bleed/shaft	5	5	5
Climb	Climb to cruise altitude	Not operated in flight	--	--	--
			(Group I)	(Group II)	(Group III)
		Duty Cycle Time, min =	40	80	180

TABLE 13

SUMMARY OF EXHAUST EMISSIONS FORMATION RATE FOR AUXILIARY POWER UNITS ON-BOARD COMMERCIAL AIRCRAFT

APU	Application	Sample Size Tested	Emission Species	Formation Rate[1] Avg, lb/hr	Duty Cycle Time, hrs[2]	Formation Rate Duty lb/Cycle	No. of APUs Delivered (Approx)[3]	No. of APUs Installed[3] (Estimated)	Operating Time[4] hrs/yr/APU Estimated	Approximate Formation Rate by Group, Tons/yr
GROUP I										
GTCP30-92	Executive Aircraft	2	CO_2	212.0	0.67	142.0	230	160	1,000	17,000
			CO	0.38		0.25				30
			HC (hot)	0.007		0.005				1
			NOx	0.237		0.159				2
GTCP36-6	Grumman Gulfstream II	2	CO_2	455.0	0.67	305.0	140	95	1,500	32,400
			CO	1.39		0.93				99
			HC (hot)	0.009		0.006				1
			NO_x	0.72		0.48				51
GROUP II										
APU	Application									
GTCP85-98/CK	Boeing 727	9	CO_2	804.0	1.33	1,070.0	1,045			2×10^6
GTCP85-98D	Douglas DC-9	2	CO	3.04		4.04	790	1,870	2,800	7,958
GTCP85-115	BAC 1-11/400	3	HC (hot)	0.122		0.162	325			320
GTCP85-129	Boeing 737	1	NOx	1.30		1.73	335			3400
GTC85-90/90B	Ground Cart[5]	3	CO_2	654.0	0.167	109.0	940	705	1,000	234,000
			CO	3.46		0.578				1,237
			HC (hot)	0.018		0.003				6
			NOx	0.954		1.59				341
GROUP III										
APU	Application									
GTCP660-4	Boeing 747	2	CO_2	2,867.0	3.0	8,601.0	225	170	2,200	402,000
			CO	8.82		26.5				1,237
			HC (hot)	0.394		1.18				55
			NOx	5.42		16.3				760
TSCP700-4	McDonnell-Douglas DC-10	2	CO_2	1,513.0	3.0[6]	4,539.0	15	3	1,000	1,702
			CO	0.666		2.00				1
			HC (hot)	0.875		2.62				7
			NOx	4.56		13.35				5
								ESTIMATED TOTAL EMISSION RATE, TONS/YEAR	CO_2	3×10^6
									CO	10,562
									HC	383
									NC_x	4,545

NOTES:

(1) Formation rates are averaged by groups from emissions performance data reduction printout, Appendix B, for power setting number 15 (full load) except GTC85-90/90B Ground Cart operation evaluated at bleed only (power setting number 5).

(2) Duty cycle time from Table 12 and customer survey results.

(3) Approximate number as of end of May, 1971. Installed APUs represent about 75 percent delivered APUs.

(4) Estimated from Table 9 and Field Service sources.

(5) Used for starting 707, 720, and DC-8 aircraft and emergency starting of other APU on-board aircraft.

(6) Not in service at this time. Estimates based on same duty cycle as 660-4 APU.

(7) Engines tabulated under each of the above groups do not constitute all engine or aircraft types in service.

evaluation of formation rates based on all the auxiliary power units sampled, as a single family, is not possible. However, emission index, lb pollutant/1000 lb of fuel consumed, is independent of fuel flow and engine size. Therefore, a statistical evaluation can be made and is presented as Table 14. As is shown in the table out of the 26 engine sample size, four engines could not be included in a single hydrocarbon family and two engines could not be included in the nitric oxide or total oxides of nitrogen sample family because the data fell outside of the three sigma deviation from the mean. GTCP85-98D, S/N P-15541 and GTCP85-98, S/N P-27857 engines did not conform to the single family statistical test on hydrocarbon emissions. At an equivalence ratio of about 0.28, signifying maximum load conditions, on page 4, Figure 1 and on page 45 of Appendix C shows these two units to exhibit obviously higher hydrocarbon emissions than the remaining lists of 85 Series engines tested. Also note that these were overhaul engines as shown in Table 4.

Similarly, the two TSCP700-4 engines tested did not conform to a single family sample test on hydrocarbons, NO, and NO_X emissions.

If the auxiliary power units were to be emissions limited based on the emission index for each then the AiResearch sample family of APU's, excluding the TSCP700-4, would conform to the following upper control limits of emission index values:

3.211 for CO_2
31.48 for CO
0.921 for HC(hot)
4.363 for NO, and
7.708 for NO_X as given in Table 14.

In order for emission formation rates to be considered for statistical comparisons a reduction of data could be made on a brake

TABLE 14

STATISTICAL EMISSIONS RESULTS FOR AIRESEARCH GAS TURBINE AUXILIARY POWER UNITS (AS SINGLE FAMILY OF 26 ENGINES AT FULL-LOAD EGT AND ENGINE POWER SETTING 15)

				Basis Two-Sided 95-Percent Probability Tables	
Emission	Sample Size Conforming	Sample Mean Emission Index LB/1000 LB Fuel*	Sample Standard Deviation	Tolerance Interval to Contain at Least 99-Percent of the Population	Confidence Interval to Contain the Population Mean
				Lower Limit Upper Limit	
CO_2	26	3.148 $\frac{LB}{LB}$ Fuel	0.0176	3.084 to 3.211	3.141 to 3.155
CO	26	11.740	5.54	0 to 31.48	9.444 to 14.035
HC (HOT) (AS CH_4)	22	0.223	0.184	0 to 0.921	0.132 to 0.314
NO	24	2.659	0.471	0.955 to 4.363	2.454 to 2.864
NO_x (AS NO_2)	24	4.928	0.769	2.147 to 7.708	4.593 to 5.262

*Except as noted.

NOTES:

1. Engine Power setting reference number 15 represents a combination load comprised of shaft load and approximately 50 percent maximum bleed air extraction load to the maximum rated exhaust gas temperature, EGT.

2. Sample size conforming to statistical test is based on a 3-sigma sample standard deviation from the sample mean.

3. Four engines did not conform to HC sample family: GTCP85-98D (S/N P-27857), GTCP85-98 (S/N P-15541), and each of the 2 TSCP700-4 tested.

4. Both TSCP700-4 engines did not conform to the NO and NO_x sample family.

specific emission formation rate basis, defined as lb/Bhp hr, to determine if the principles of statistics can be applied to the data.

As for the average emission formation rate calculations for propulsion engines, special significance lies in the fact that they can be compared to piston-engine light aircraft emissions results as shown in Reference 1 or be used as an approximation of the absolute value of emissions generated by turboprop aircraft in the vicinity of airports. The list of references are included at the end of this section. Consideration has been given to two aircraft service cycles: (1) takeoff-cruise-landing and (2) landing-takeoff evaluated under 3000 feet as suggested by the Air Pollution Control Office in Reference 2.

Table 15 shows the average emission formation rates for a comparable range of power settings for the test load conditions and duty cycle load conditions for a four turboprop engine sample. Table 16 shows the estimated duty cycle times in each mode, the corresponding generated emission weight for time in mode together with emissions in pounds generated for each aircraft service cycle, and the total emission formation rate per year for 80 percent of all turboprop engines delivered to customers estimating each customer operates his respective aircraft 750 cycles per year.

Table 17 presents a statistical analysis based on emission index or mole percent for CO_2 for a four turboprop engine sample. It serves only to show that for a 95 percent probability that 99 percent of the total population existing can be represented by this sample then the upper control limit for the emission index for CO_2 must be 3.270 rather than 3.155, CO must be 6.679 instead of 1.489, HcH must be 6.169 rather than 0.845, and NO_x must be 28.31 rather than 9.930. The high upper limit is a result of 8.3 standard deviations being required for an engine sample size of four which illustrates the need for a larger sample size if a high assurance of conforming to a sample family is desired.

TABLE 15

AVERAGE EMISSIONS FORMATION RATES FOR FOUR TURBOPROP (TPE331/T76) PROPULSION ENGINES

At Test Load Conditions

Test Power Setting	Percent Power, Avg.	Avg. Emission Formation Rate, lb/hr			
		CO_2	CO	HC (hot) (as methane)	NO_x (as NO_2)
1	0.4 gnd. idle	241.0	3.55	3.28	0.237
2	6.0 flt. idle	489.0	3.70	0.858	1.12
6	30.0	653.0	2.96	0.331	1.67
11	53.2	833.0	2.15	0.088	2.30
16	74.4	997.0	1.12	0.047	3.00
20	91.5	1149.0	0.552	0.031	3.60

At Duty Cycle Load Conditions

Operating Mode	Percent Power, Avg.	Avg. Emission Formation Rate, lb/hr			
		CO_2	CO	HC (hot) (as methane)	NO_x (as NO_2)
idle-taxi	15	550.0	3.42	0.66	1.33
descent/ approach	30	653.0	2.96	0.331	1.67
run-up/hold	50	809.0	2.26	0.120	2.22
cruise	90	1136.0	0.60	0.032	3.55
take-off/ climb	100	1225.0	0.269	0.023	3.90

TABLE 16

AVERAGE WEIGHT OF EMISSIONS GENERATED DURING EACH OPERATING MODE OF AIRESEARCH TURBOPROP (TPE331/T76) POWERED AIRCRAFT

				Emission Weight for Time in Mode, lb			
Aircraft Operating Mode	Description	Percent Max Rated Power	Approximate Time in Mode (minutes)	CO_2	CO	HC (hot) As CH_4	NOx As No_2
Ground idle	Engine startup and taxi to end of runway	15	5	45.8	0.285	0.055	0.111
Run-up	Check out at end of runway	50	2	26.9	0.075	0.004	0.074
Initial climb	Take-off and climb to 3000 feet	100	3	61.2	0.013	0.001	0.195
Final climb	Climb to cruise altitude (over 3000 feet)	100	7	142.9	0.031	0.003	0.455
Cruise	(Not pertinent to pollution near airport)	90	30	568.0	0.300	0.016	1.775
Inital descent	Descend to landing pattern altitude of 3000 feet	30	10	108.9	0.493	0.055	0.278
Cruise pattern	Hold in landing pattern at 3000 feet	50	2	26.9	0.075	0.004	0.074
Final approach	Descend from 3000 feet and land	30	2	21.8	0.100	0.011	0.056
Ground idle	Taxi back to hanger	15	2	18.3	0.114	0.022	0.044
	Takeoff-Cruise-Landing Cycle, TCL	TOTAL	63	1,021.0	1.486	0.171	2.362
	Landing Takeoff Cycle, LTC	TOTAL	16	201.0	0.662	0.097	0.554

TOTAL EMISSIONS FORMATION RATE, TONS/YR

TCL Cycle	462,000	673	77	1070
LTC Cycle	91,000	300	44	250

NOTES:

1. Emissions weight data based on emissions formation rates shown on Table for 4 engines tested.
2. Emissions data in tons/yr based on information provided by AiResearch Flight Operations Department and customer surveys. An estimated 80 percent of 467 engines sold through May 1971 are in active service and reflect an estimated 750 duty cycles per year (about 2 per day) per engine.

TABLE 17

STATISTICAL EMISSIONS RESULTS FOR FOUR AIRESEARCH TURBOPROP PROPULSION ENGINES UNDER MAXIMUM SHAFT LOAD

				Basis Two-Sided 95% Probability Tables	
Emission	Sample Size	Sample Mean Emission Index LB/1000 LB Fuel*	Sample Standard Deviation	Tolerance Interval To Contain at Least 99% of the Population	Confidence Interval To Contain the Population Mean
CO_2	4	3.155 LB/LB Fuel	0.013	3.045 to 3.270	3.136 to 3.179
CO	4	1.489	0.604	0 to 6.679	0.494 to 2.483
HC (HOT) (as CH_4)	4	0.845	0.620	0 to 6.169	0 to 1.865
NOx (as NO_2)	4	9.930	2.140	0 to 28.31	6.400 to 13.45

*Except as noted

NOTES:

1. Sample size conforming to statistical test is based on a 3-sigma sample standard deviation from the sample mean.

The statistical information generated from both APU and propulsion engine data leads to one observation. That is, a statistical definition of upper emissions levels that would include a high proportion of an existing gas turbine population is not considered practical. This is because emissions levels of identically designed production gas turbines vary by such large amounts that a statistical upper control limit to include a high percentage of an existing population becomes unreasonably high.

REFERENCES

1. "A Study of Exhaust Emissions From Reciprocating Aircraft Power Plants." Scott Research Laboratories, Inc., APCO Contract CPA 22-69-129, December, 1970.

2. "Role of NAPCA in Controlling Aircraft Pollutant Emissions." SAE paper 710338 by Kittredge G.D. and McNutt B.D., National Air Polution Control Administration.

3. "Measuring Gaseous Emissions From an AirCraft Turbine Engine." SAE paper 700249 by Chase J.O. and Hurn R.W., U.S. Bureau of Mines, April, 1970.

4. "The Current and Future Basis for Aircraft Air Pollution Control." SAE paper 710339 by William T. Westfield, FAA.

5. "Procedure for the Continuous Sampling and Measurement of Gaseous Emissions from Aircraft Turbine Engines." SAE E-31 Committee Final Draft, May 25, 1971, R.W. Hurn, Chairman, U.S. Bureau of Mines, Bartlesville, Oklahoma.

6. "CRC Evaluation of Aviation Emission-Measurement Techniques." SAE paper 700338 by T.O. Wagner, American Oil Company, April, 1970.

7. "Fundamental Processes Controlling the Air Pollution Emissions from Turbojet Engines." AIAA paper 69-1040 by R.F. Sawyer, University of California, October, 1969.

8. Clean Air Ammendments of 1970, Congressional Record-House, December 17, 1970.

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

Baseline exhaust emissions levels have been successfully determined as requested under Contract 68-04-0022 with the Environmental Protection Agency, Office of Air Programs for the specified AiResearch commercial auxiliary power and propulsion gas turbine engines used in aircraft-related applications. Two notable conclusions derived from this test program are as follows:

(a) A large variation in exhaust emissions test results was observed for several engines tested, particularly emissions sampled on the 85 Series engines. As Figures 1 through 4 in the Summary, Section 2.0 illustrates; a wide band of emissions levels over the equivalence ratio or engine load range exists and covers two orders of magnitude on the emission index. This characteristic may be attributed primarily to the combustor related-components of 85 Series engines.

(b) The differences in emissions measurements that resulted from the various probe measuring techniques used in this test program suggests the need for additional comparison studies on a larger number and variety of gas turbine engines. Since the 12-point fixed (averaging) probe and movable sampling probe was used to obtain emissions data for only one engine test, a preference for either probe technique is not justified. However, the error expected from using the 12-point averaging probe was considerably less than the variation in emissions levels observed for two engine models having identically designed hardware.

6.2 Recommendations

Since emissions test results varied significantly in tests conducted on engines that contain identically designed hardware, several recommendations are in order.

For any given engine model, such as the GTCP85-98, a study should be conducted to determine why sizeable emissions differences exist from one set of hardware to another.

Test and study efforts should be conducted to determine the effects of combustor related parameters such as fuel pressure, fuel droplet size, spray angle, mixing effects, and combustor installation orientation on emissions levels. This effort would also have to be related to the formation chemistry processes.

A study of the kinetics of the formation chemistry processes of hydrocarbons, carbon monoxide, and oxides of nitrogen, and the relationship of these processes to existing combustion systems tested under this contract is recommended.

A larger quantity of engines should be sampled in the 30, 36, 660, 700, 731, and 231 Series. One and two engine sample sizes are not sufficient to establish representative emissions data. A minimum of a 3 to 4 engine sample size is recommended although 8 to 10 is preferred.

A comparison of emissions index in lb/1000 lb fuel consumed does not give a fair evaluation of engines with different thermal efficiencies since two engines with the same emissions index could develop different horsepowers. Therefore, a brake specific emissions index in lb/Bhp x 1000 lb fuel consumed and a brake specific formation rate in lb/Bhp hr is a more reasonable comparison for engines with different thermal efficiencies or different duty cycles. For bleed engine evaluation, the pressure-volume (pv) work delivered to the aircraft bleed system should be evaluated as available power for the brake specific calculations.

The evaluation of emissions on a brake specific basis would give renewed support the possibility of statistical study of various engine sizes in a single family comparison.

A. ANALYZER INSTRUMENTATION

This section reviews the gas analyzers and their principles of operation as used to conduct emissions measurements at AiResearch facilities.

A.1 Heated Hydrocarbon Analyzer (Beckman Model 402)

The hydrocarbon analyzer, Figure A-1, is designed to measure the total hydrocarbon contents of exhaust emissions from gasoline, diesel, gas turbine, and jet engines. The analysis is based on flame ionization, a highly sensitive detection method.

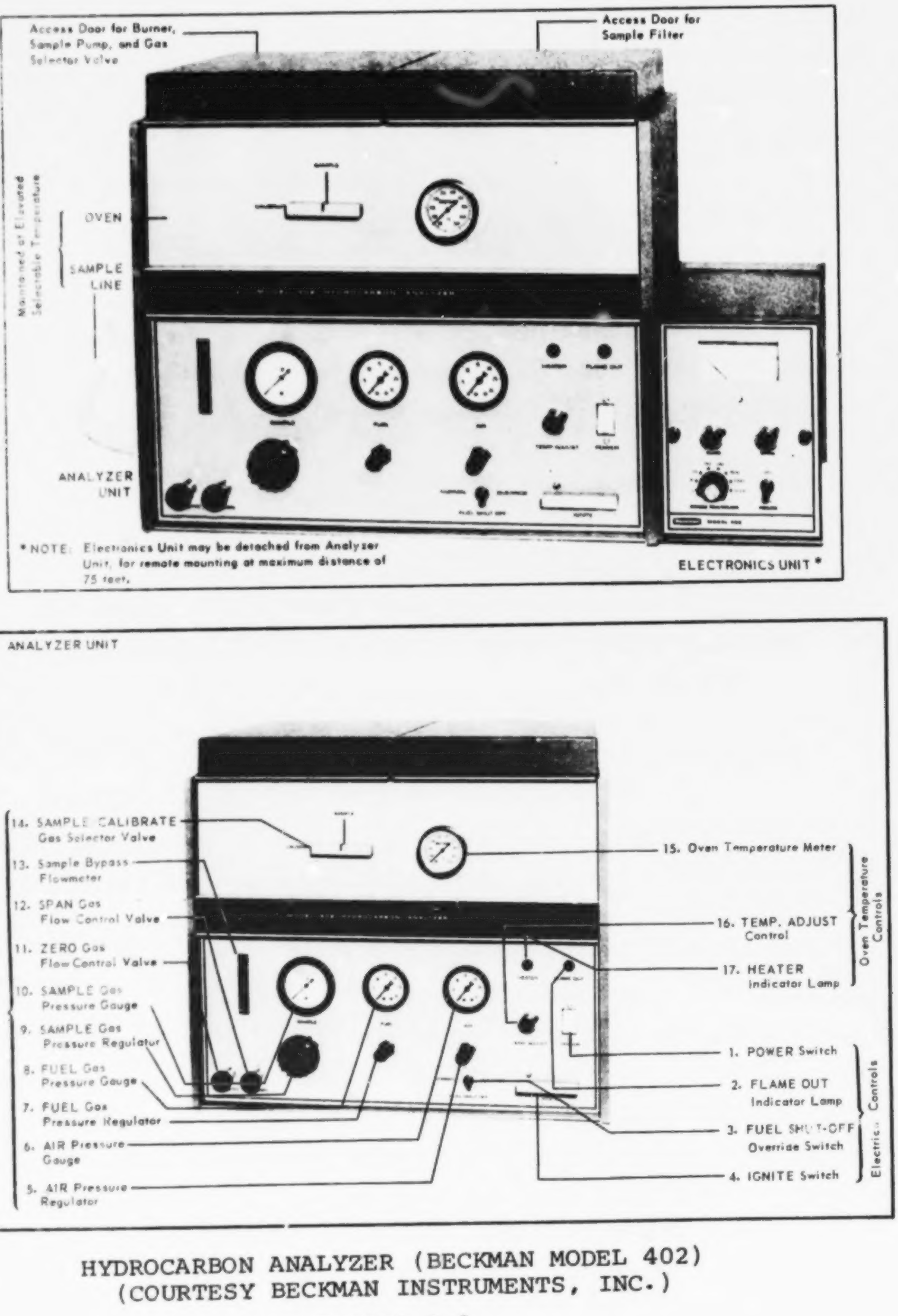
The instrument consists of:

(1) Heated, temperature-controlled sample line.

(2) Analyzer unit, incorporating a flame-ionization detector and associated sample-handling system, with critical sample-handling components contained within a temperature-controlled oven.

(3) Electronics unit, containing an electrometer amplifier and associated circuitry, readout meter, and recorder output provisions. The electronics unit is attached directly to the analyzer unit as shown in Figure A-1.

Sample from the source is drawn into the analyzer through the sample line. To prevent the loss of higher-molecular-weight hydrocarbons, the sample is maintained at an elevated temperature during its passage through the sample line and the interior of the analyzer. Temperature setpoint for both the sample line and the analyzer oven was 310°F for the tests carried out in this report.


Access Door for Burner, Sample Pump, and Gas Selector Valve
Access Door for Sample Filter
Maintained at Elevated Selectable Temperature
OVEN
SAMPLE LINE
ANALYZER UNIT
ELECTRONICS UNIT *
A. ANALYZER UNIT
Gas Controls
14. SAMPLE CALIBRATE Gas Selector Valve
13. Sample Bypass Flowmeter
12. SPAN Gas Flow Control Valve
11. ZERO Gas Flow Control Valve
10. SAMPLE Gas Pressure Gauge
9. SAMPLE Gas Pressure Regulator
8. FUEL Gas Pressure Gauge
7. FUEL Gas Pressure Regulator
6. AIR Pressure Gauge
5. AIR Pressure Regulator
15. Oven Temperature Meter
16. TEMP. ADJUST Control
17. HEATER Indicator Lamp
Oven Temperature Controls
1. POWER Switch
2. FLAME OUT Indicator Lamp
3. FUEL SHUT-OFF Override Switch
4. IGNITE Switch
Electrical Controls

*NOTE: Electronics Unit may be detached from Analyzer Unit, for remote mounting at maximum distance of 75 feet.

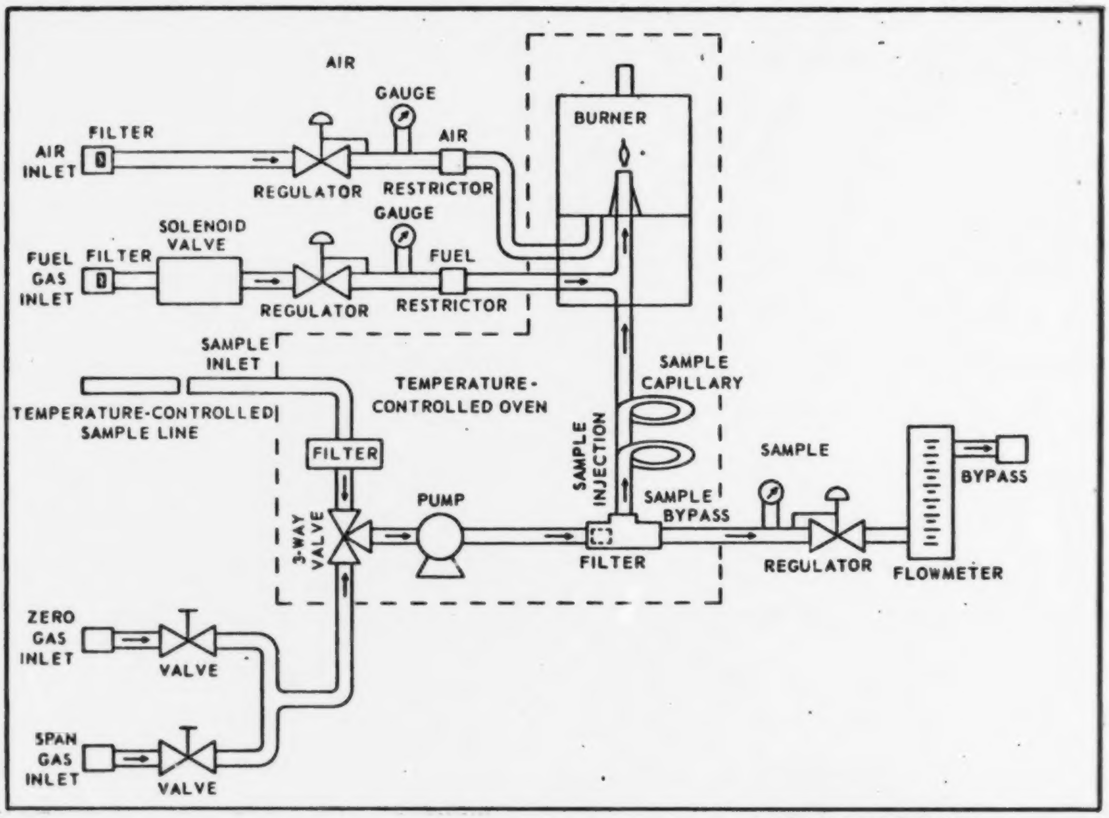
HYDROCARBON ANALYZER (BECKMAN MODEL 402)
(COURTESY BECKMAN INSTRUMENTS, INC.)

FIGURE A-1

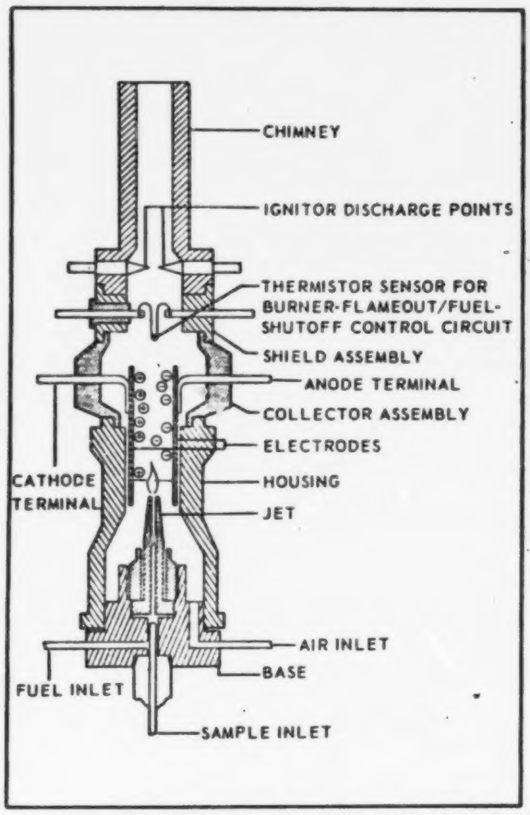
The hydrocarbon sensor is in a burner where a regulated flow of sample gas passes through a flame sustained by regulated flows of a fuel gas and air. The flame formed when fuel gas (hydrogen diluted with an inert gas) burns in air contains an almost negligible number of ions. Introduction of traces of hydrocarbons into such a flame, however, produces a large amount of ionization. Within the flame, the hydrocarbon components of the sample stream undergo ionization, producing electrons and positive ions. Polarized electrodes collect these ions, causing current to flow through measuring circuitry located in the electronics unit. The ionization current is proportional to the rate at which carbon atoms enter the burner and is therefore a measure of the concentration of hydrocarbons in the original gas sample.

The flow diagrams for the analyzer and burner are shown in Figure A-2. A stainless-steel bellows-type positive displacement pump of four cu ft/min capacity draws the sample into the analyzer and through a glass fiber filter that removes particulate matter. The sample is then supplied to the burner under positive pressure. An internal sample-bypass arrangement provides high-velocity sample flow through the analyzer, thus minimizing system response time. A front-panel flowmeter indicates bypass flow. Since the ionization level is related to the flow rate of sample through the flame, the flowmeter must be set to read a sample flow identical to the calibration gas flow. The analyzer has rear-panel inlet ports for connection of suitably pressurized zero and span standard gases. Flow of each standard gas is controlled by a corresponding front-panel needle valve. A front-panel three-way valve permits selection of either the actual sample or the desired standard gas (i.e., "zero gas" or "span gas" referenced in Figure A-2) used in calibrating the instrument.

The oven, which uses air-bath heating, is maintained at the selected temperature by a solid-state temperature controller utilizing a thermistor sensor. A vertical partition divides the oven into


AIR
GAUGE
AIR
FILTER
AIR INLET
REGULATOR
RESTRICTOR
BURNER
SOLENOID VALVE
GAUGE
FUEL GAS INLET
FILTER
FUEL
REGULATOR
RESTRICTOR
SAMPLE INLET
TEMPERATURE-CONTROLLED OVEN
SAMPLE CAPILLARY
TEMPERATURE-CONTROLLED SAMPLE LINE
FILTER
SAMPLE INJECTION
SAMPLE
BYPASS
3-WAY VALVE
PUMP
SAMPLE BYPASS
FILTER
REGULATOR
FLOWMETER
ZERO GAS INLET
VALVE
SPAN GAS INLET
VALVE

FLOW DIAGRAM


CHIMNEY
IGNITOR DISCHARGE POINTS
THERMISTOR SENSOR FOR BURNER-FLAMEOUT/FUEL-SHUTOFF CONTROL CIRCUIT
SHIELD ASSEMBLY
ANODE TERMINAL
COLLECTOR ASSEMBLY
ELECTRODES
CATHODE TERMINAL
HOUSING
JET
AIR INLET
BASE
FUEL INLET
SAMPLE INLET

BURNER DIAGRAM

SPECIFICATIONS

Analysis Temperature	Adjustable from 200°F to 400°F
Line Voltage	107-127 VAC. 50/60 Hz, 1000 watts max.
Ambient Operational Temperature	32°F to 110°F
Ambient Operational Humidity	95% R.H.
Potentiometric Output	10 mV, 100 mV, 1V
Sensitivity	5 ppm to 10% full scale as CH_4 with H_2/N_2 or H_2/He Fuel
Ranges	X1, X5, X10, X50, X100. X500, X1000, X5000 with continuous electronic span adjustment
Response	Less than 1 second for 90% of final reading (with CH_4 from analyzer input without sample probe)
Electronic Stability	±1% full scale/24 hrs. with less than 10° ambient temperature change
Repeatability	±1% full scale for successive samples
Temperature Controlled Probe	10 ft. length, teflon surface in contact with sample (proportional temperature controlled and adjustable from 200°F to 400°F)

HEATED HYDROCARBON ANALYZER SPECIFICATIONS AND DIAGRAMS
(FIGURES COURTESY OF BECKMAN INSTRUMENTS, INC.)

FIGURE A-2

two compartments with separate doors. The left-hand compartment contains the burner, the sample pump, and the three-way gas-selector valve. The right-hand compartment contains only the sample filter and permits access to the filter without disturbing temperature equilibrium of the other elements.

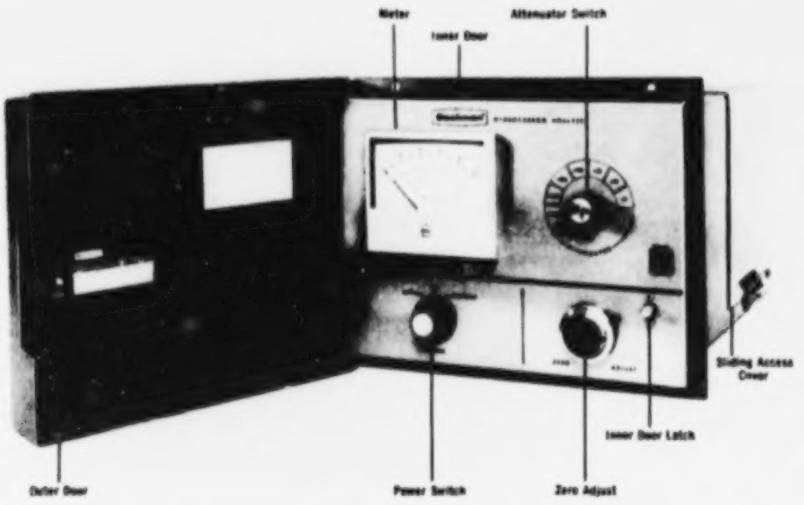
Within the analyzer, the fuel gas is routed to the burner through a solenoid valve controlled by the burner-flameout/fuel-shutoff circuitry. A thermistor sensor continuously monitors the status of the burner flame. In event of flameout, the valve closes to stop the flow of fuel gas; simultaneously, a front-panel indicator illuminates to alert the operator.

The electronics unit has front-panel controls for range selection and adjustment of zero and span. Readout is on a front-panel meter calibrated linearly from 0 to 100. In addition, a selectable output of 10 mv, 100 mv, or 1 volt is available to drive a voltage-type recorder.

A.2 Cold Hydrocarbon Analyzer (Beckman Model 108A)

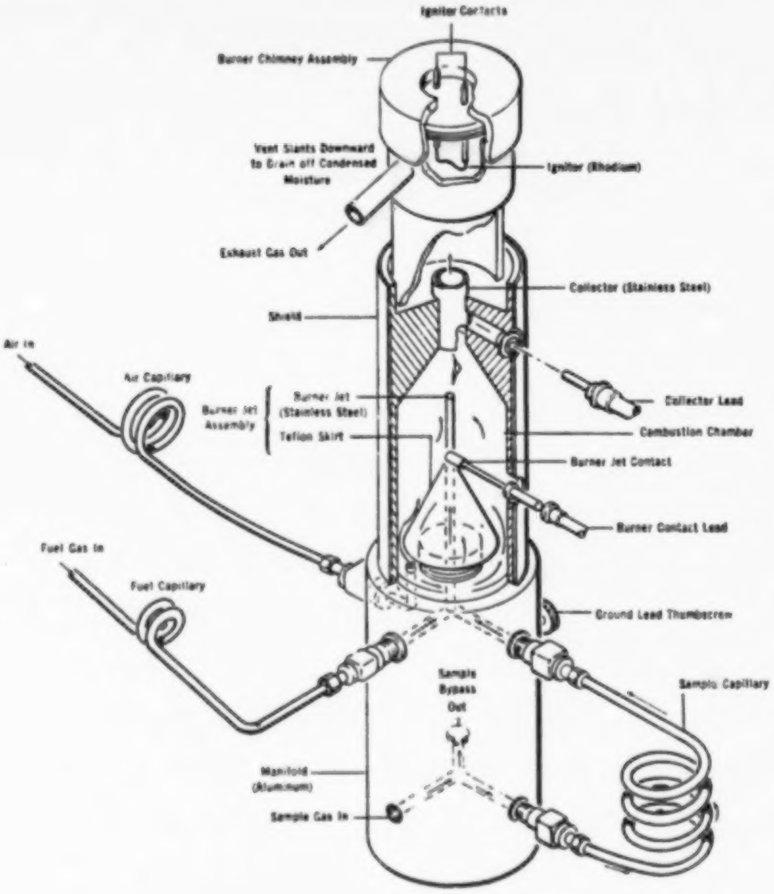
The cold hydrocarbon analyzer (Figure A-3) continuously monitors the hydrocarbon content of a cold sample gas stream. This instrument also uses the flame ionization method of detection (FID) by measuring the concentration of carbon ions released by a sample gas passing through a burner.

This analyzer differs from the heated hydrocarbon analyzer in that it contains no built-in sample pump, heated sample line controls, oven, or fuel shutoff safety devices. Although the burner configuration (Figure A-3) is geometrically different than the heated analyzer, any differences in readings between the two analyzers have been


Meter
Inner Door
Attenuator Switch
Sliding Access Cover
Inner Door Latch
Outer Door
Power Switch
Zero Adjust

FRONT VIEW WITH OUTER DOOR OPEN

MODEL 108A PANEL-MOUNTED HYDROCARBON ANALYZER


Igniter Contacts
Burner Chimney Assembly
Vent Slants Downward to Drain off Condensed Moisture
Igniter (Rhodium)
Exhaust Gas Out
Collector (Stainless Steel)
Shield
Air In
Air Capillary
Burner Jet Assembly
Burner Jet (Stainless Steel)
Teflon Skirt
Collector Lead
Combustion Chamber
Burner Jet Contact
Burner Contact Lead
Fuel Gas In
Fuel Capillary
Ground Lead Thumbscrew
Sample Bypass Out
Sample Capillary
Manifold (Aluminum)
Sample Gas In

BURNER ASSEMBLY (WITH CAPILLARIES ATTACHED)

COLD HYDROCARBON ANALYZER AND BURNER ASSEMBLY
(COURTESY BECKMAN INSTRUMENTS, INC.)

FIGURE A-3

attributed to condensation of the higher molecular weight hydrocarbons in the sample and analyzer lines, resulting in lower readings for the cold FID instrument.

For this test program, the cold FID analyzer was used in addition to the heated FID analyzer for sampling the first engines. Sample was brought through ten feet of heated sample line to the hot FID analyzer and then divided with an additional six feet of the line to the cold FID analyzer. Both instruments were calibrated on the same zero and span gases such that instrument readout differences are attributable primarily to the cold sample line.

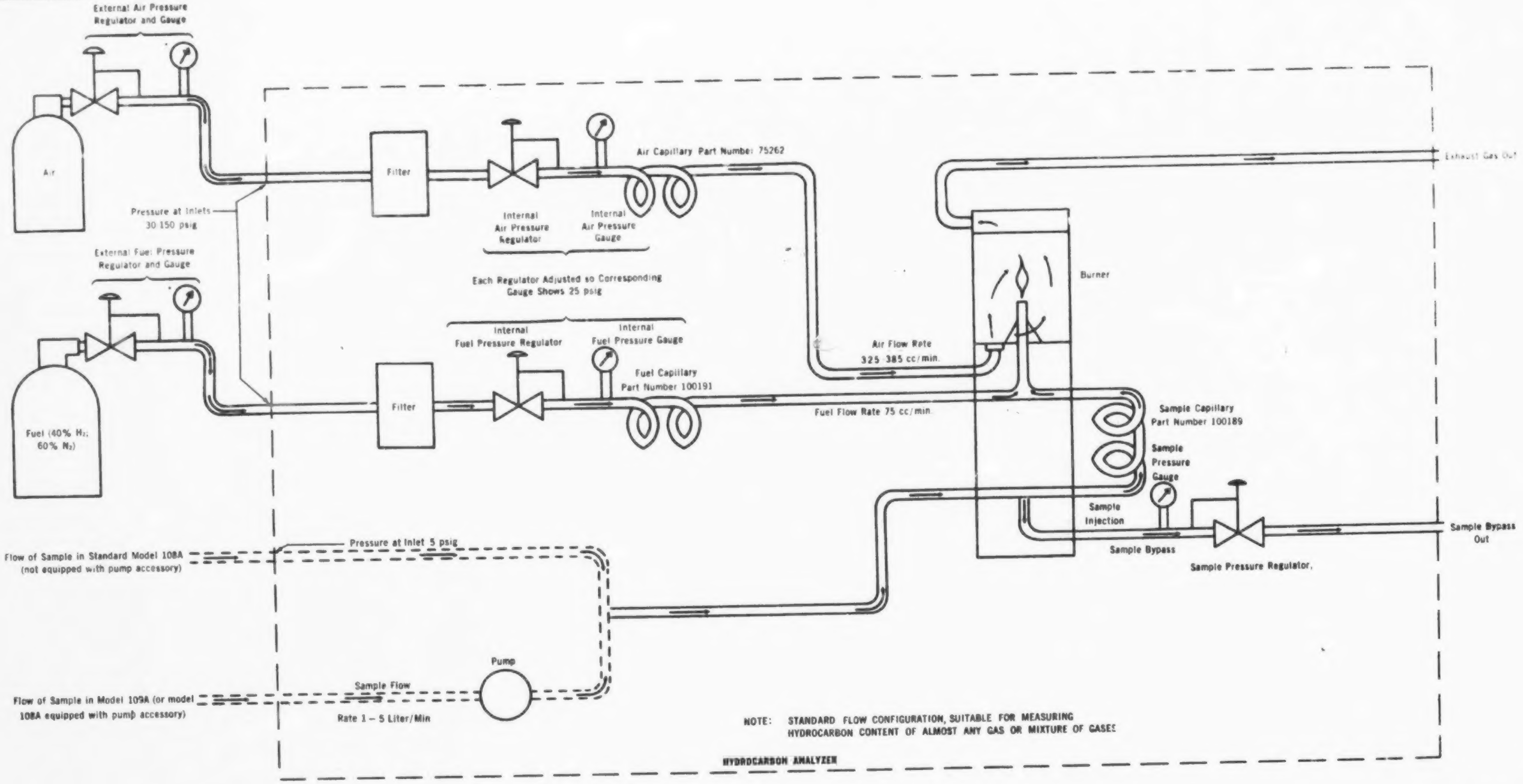
A flow diagram of the cold FID system is shown in Figure A-4.

A.3 Chemiluminescent/NO - NO_x Analyzer

The chemiluminescent analyzer is packaged as four separate units: (1) control unit, (2) an analyzer unit, (3) a reaction chamber mechanical vacuum pump, and (4) a converter for the thermal conversion of NO_2 to NO. For these tests, a Thermo Electron Corporation analyzer model 10A was used, which was operated in the NO_x and NO modes.

A typical arrangement of the Model 10A chemiluminescent analyzer is shown in Figure A-5. Other equipment needed for use with the analyzer are the NO and NO_2 standard gases, an oxygen source for the ozone generator, and an accumulator and suitable sample bypass pump to provide two to two and one-half cu ft/hr sample flow.

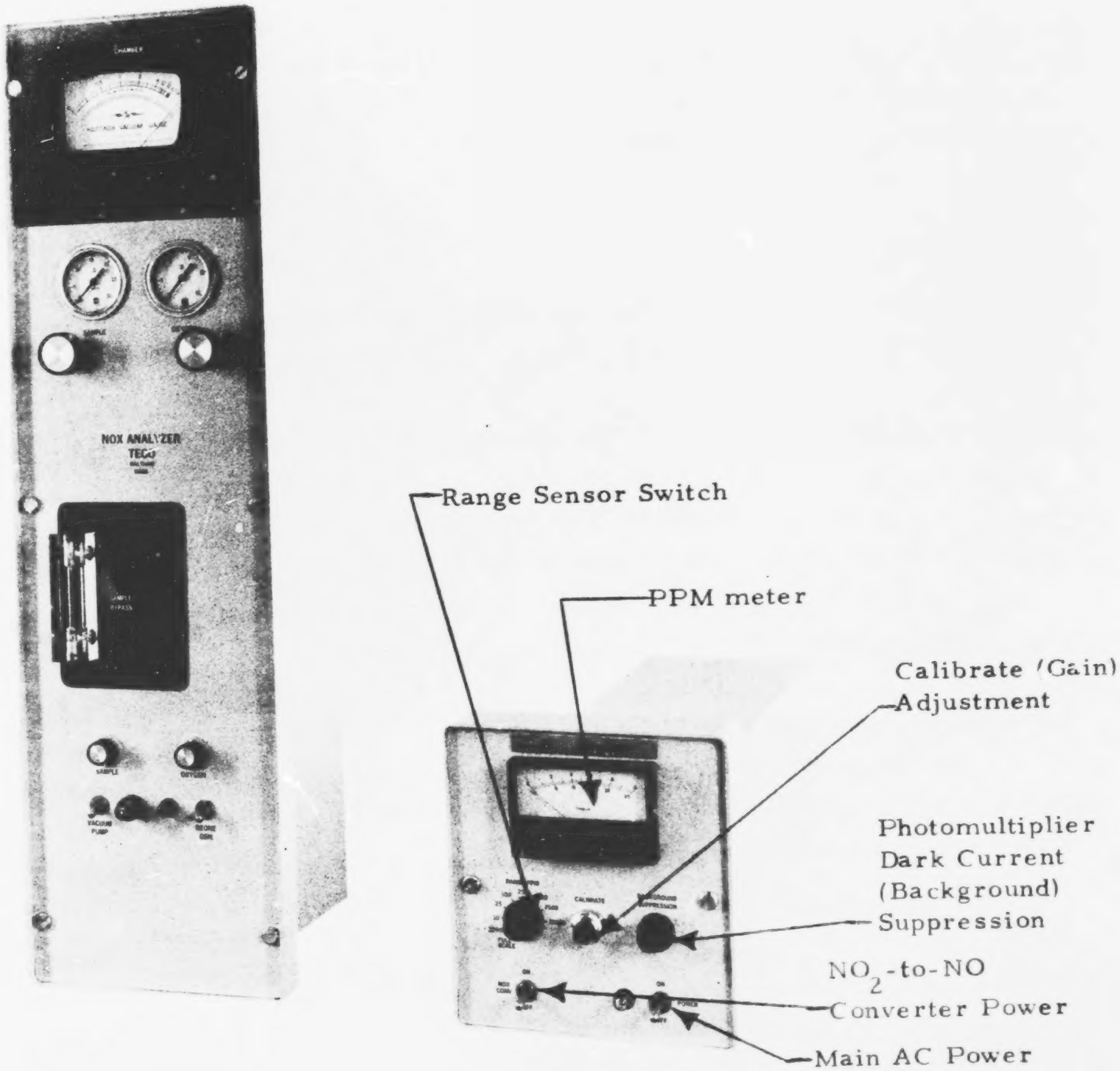
The control unit contains the switch for selection of sensitivity from seven available full-scale ranges (10, 25, 100, 250, 1000, 2500, and 10,000 ppm) and potentiometers which provide for instrument calibration.


External Air Pressure Regulator and Gauge
Air
Pressure at Inlets 30-150 psig
External Fuel Pressure Regulator and Gauge
Fuel (40% H₂; 60% N₂)
Filter
Internal Air Pressure Regulator
Internal Air Pressure Gauge
Air Capillary Part Number 75262
Each Regulator Adjusted so Corresponding Gauge Shows 25 psig
Internal Fuel Pressure Regulator
Internal Fuel Pressure Gauge
Fuel Capillary Part Number 100191
Filter
Air Flow Rate 325-385 cc/min.
Fuel Flow Rate 75 cc/min.
Burner
Exhaust Gas Out
Sample Capillary Part Number 100189
Sample Pressure Gauge
Sample Injection
Sample Bypass
Sample Pressure Regulator.
Sample Bypass Out
Flow of Sample in Standard Model 108A (not equipped with pump accessory)
Pressure at Inlet 5 psig
Flow of Sample in Model 109A (or model 108A equipped with pump accessory)
Sample Flow
Rate 1 – 5 Liter/Min
Pump
NOTE: STANDARD FLOW CONFIGURATION, SUITABLE FOR MEASURING HYDROCARBON CONTENT OF ALMOST ANY GAS OR MIXTURE OF GASES
HYDROCARBON ANALYZER

*This regulator must be set at least 5 psi above pressure of internal regulator. Minimum permissible pressure must be determined experimentally.

COLD HYDROCARBON ANALYZER FLOW DIAGRAM
(COURTESY OF BECKMAN INSTRUMENTS, INC.)

FIGURE A-4


NOX ANALYZER
TECO
Range Sensor Switch
PPM meter
Calibrate (Gain) Adjustment
Photomultiplier Dark Current (Background) Suppression
NO2-to-NO Converter Power
Main AC Power

ANALYZER UNIT

CONTROL UNIT

MODEL 10 CHEMILUMINESCENT ANALYZER (CONTROL AND ANALYZER UNITS)

FIGURE A-5

MP-30252

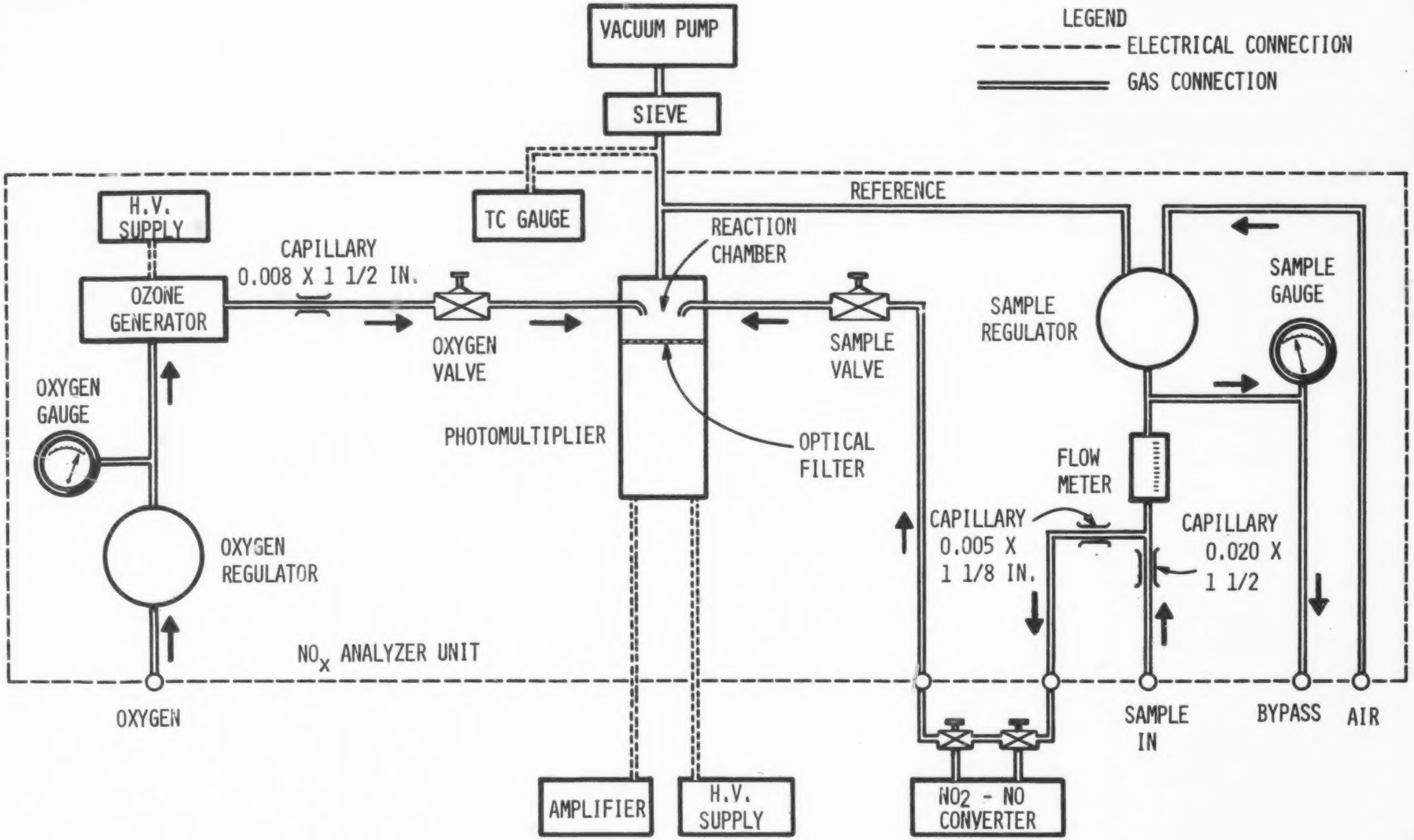
The analyzer unit contains the reaction chamber, the photomultiplier tube, the ozonator, the ozonator power supply, the oxygen and gas sample lines, capillaries, and pressure regulators.

Figure A-6 presents a schematic drawing of the entire chemiluminescent instrument with the portion inside the dashed rectangle representing the analyzer unit. The heart of the analyzer is the cylindrical reaction chamber where sample gas containing NO molecules mixes with O_3 molecules from the ozonator. Electronically excited NO_2 molecules are created that emit light (chemiluminescence) as the orbital electrons decay to their ground states.

The chemiluminescence is monitored through an optional filter by a high sensitivity photomiltiplier positioned at one end of the reactor. The filter-photomultiplier combination responds to light in a narrow wavelength band unique to the desired electron decay. Sample flow is controlled so that the output from the photomultiplier is linearly proportional to the NO concentration.

Oxygen, O_2, enters the analyzer unit, passing through a pressure regulator that is used to regulate the flow rate, and enters the ozonator. A fraction of the O_2 is converted to O_3, and the mixture passes through an orificing glass capillary to the reaction chamber.

Sample gas enters the instrument, passing through another glass capillary, and is bled off to the reaction chamber. That portion of the entering sample not diverted to the reaction chamber passes through a front panel flowmeter adjusted to two standard cubic feet per hour and a regulator to the instrument exhaust system. A bypass pump is used to pull the sample through the instrument. That portion of the entering gas sample diverted toward the reaction chamber is directed to the rear of the analyzer unit, where the sample gas will


LEGEND
ELECTRICAL CONNECTION
GAS CONNECTION
VACUUM PUMP
SIEVE
TC GAUGE
REFERENCE
H.V. SUPPLY
OZONE GENERATOR
CAPILLARY 0.008 X 1 1/2 IN.
OXYGEN VALVE
REACTION CHAMBER
PHOTOMULTIPLIER
OPTICAL FILTER
SAMPLE VALVE
SAMPLE REGULATOR
SAMPLE GAUGE
FLOW METER
CAPILLARY 0.005 X 1 1/8 IN.
CAPILLARY 0.020 X 1 1/2
OXYGEN GAUGE
OXYGEN REGULATOR
NO$_X$ ANALYZER UNIT
OXYGEN
AMPLIFIER
H.V. SUPPLY
NO2 - NO CONVERTER
SAMPLE IN
BYPASS
AIR

CHEMILUMINESCENT ANALYZER

FIGURE A-6

enter the converter if the instrument is operating in the NO_x mode (i.e., NO - NO_2 mixture mode). As explained below, use of the converter is unnecessary if the instrument is operating in the NO mode.

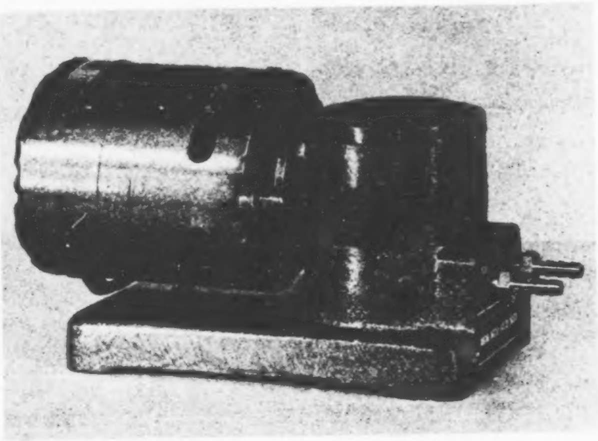
The basic chemiluminescent analyzer is only sensitive to NO molecules, as opposed to NO_2 molecules, since O_3 does not react with NO_2 to create chemiluminescence. Therefore, to measure NO_x (NO_2 + NO), the NO_2 must first be converted to NO. The conversion is accomplished by passing the sample gas through the converter, a thermally-insulated resistance-heated stainless steel coil at 1292°F. With the application of heat, NO_2 molecules in the sample gas are reduced to NO molecules. Two three-way valves located on the front of the converter direct the sample gas either through the converter to measure NO_x or past the converter to measure NO.

A Precision Scientific Company mechanical vacuum pump, Model S-35, is supplied to evacuate the analyzer reaction chamber to pressures in the 5-12 torr range. A photograph of this vacuum pump appears in Figure A-7. A metal bellows hose connects to a molecular sieve installed above the mechanical pump. The purpose of this sieve is to absorb O_3 in order to prevent breakdown of the pump oil.

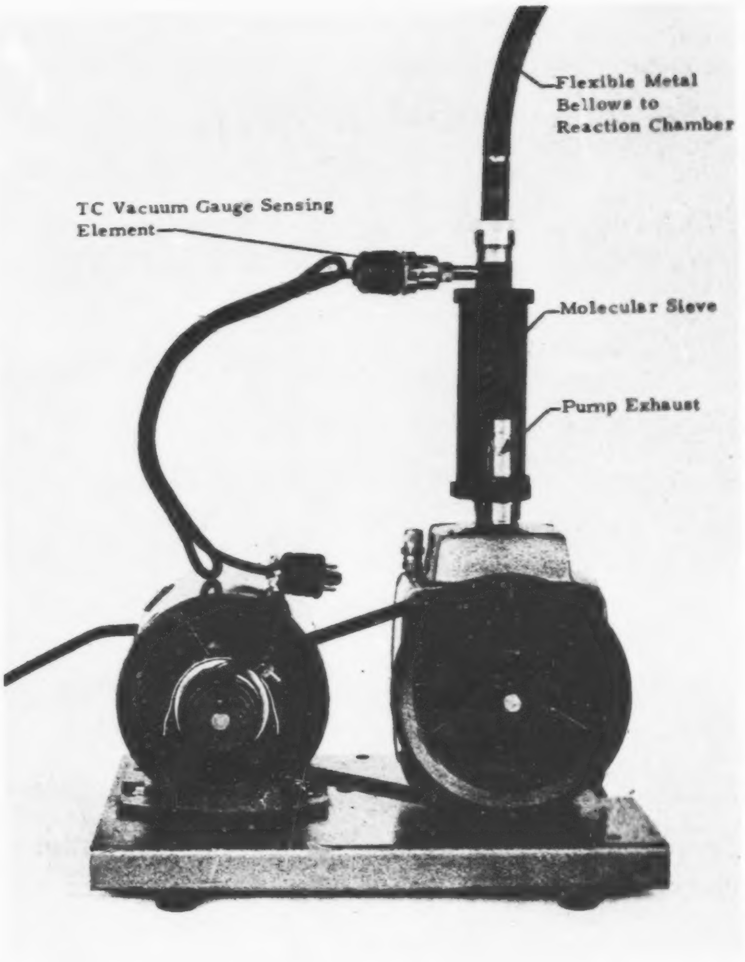
The gas sample is pulled through the instrument by a small dynapump shown together with its specification in Figure A-7, after which it is exhausted to ambient. This pump improves the overall system response by moving the flow in the main sample line by about 20 liters per minute, while each instrument in the analyzer group removes flow from the main sample line at a much lower rate.

PERFORMANCE SPECIFICATIONS FOR THE DYNA-PUMP ARE AS FOLLOWS:

Capacity, cu. in.	430
Maximum Pressure, psi	14
Maximum Vacuum, Inches Hg.	14
Strokes per Minute	3000
Motor, H.P.	1/50
Weight, lbs	5-1/2



OPTIONAL DYNA-PUMP
(i. e., SAMPLE BYPASS PUMP)


Flexible Metal Bellows to Reaction Chamber
TC Vacuum Gauge Sensing Element
Molecular Sieve
Pump Exhaust

MECHANICAL REACTION CHAMBER VACUUM PUMP
(PRECISION SCIENTIFIC CO. MODEL S-35)

VACUUM PUMPS FOR CHEMILUMINESCENT ANALYZER

FIGURE A-7

A.4 Non-Dispersive Infrared (NDIR) Analyzers for CO - CO_2

To measure the differential absorption of infrared energy, this instrument employs a double-beam optical system contained in the analyzer section. A simplified functional diagram and instrument specifications are shown in Figure A-8.

Two infrared sources are used, one for the sample energy-beam, the other for reference energy-beam. The beams are blocked simultaneously ten times per second by the chopper, a two-sigmented blade rotating at five revolutions per second. In the unblocked condition, A of Figure A-8, each beam passes through the associated cell and into the detector.

The sample cell is a flow-through tube that receives a continuous stream of sample. The reference cell is a sealed tube filled with a reference gas. This gas is selected for negligible absorption of infrared energy of those wavelengths absorbed by the sample component of interest.

The detector consists of two sealed compartments separated by a flexible metal diaphragm. Each compartment has an infrared-transmitting window, to permit entry of the corresponding energy-beam. Both chambers are filled, to the same sub-atmospheric pressure, with the vapor of the component of interest. Therefore, each chamber will absorb infrared energy from its source and will respond.

The response of the two detector chambers differs, since in operation the presence of the infrared-absorbing component of interest in the sample streams leaves less energy available for the corresponding detector chamber. There is, thus, a difference in energy levels between the sample (containing the component of interest) and the reference (non-absorbing) sides of the system. This energy difference results in the following sequence of events.

SPECIFICATIONS

MAXIMUM ZERO DRIFT:
±1% of full scale per 8 hours.

MAXIMUM SPAN DRIFT:
±1% of full scale per 24 hours.

SENSITIVITY:
0.5% of full scale.

ACCURACY:
±1%.

AMPLIFIER RESPONSE SPEED:
90% response in 0.5 second.

AMBIENT TEMPERATURE RANGE:

IR315, IR315L, −20° to +120°F.

OUTPUT (Options Available):
Current output—0 to 5 ma into 500 ohms maximum.
Voltage output—Adjustable to match any potentiometric recorder having a span of between 1 and 100 mv.

VOLTAGE AND FREQUENCY (Options Available):
115 ±15 volts, 60 ±0.5 Hz (cps); or
115 ±15 volts, 50 ±0.5 Hz (cps).

MAXIMUM POWER CONSUMPTION

IR315, 530 watts; IR315L, 640 watts.

MAXIMUM SEPARATION OF AMPLIFIER CONTROL SECTION AND ANALYZER SECTION
500 feet.

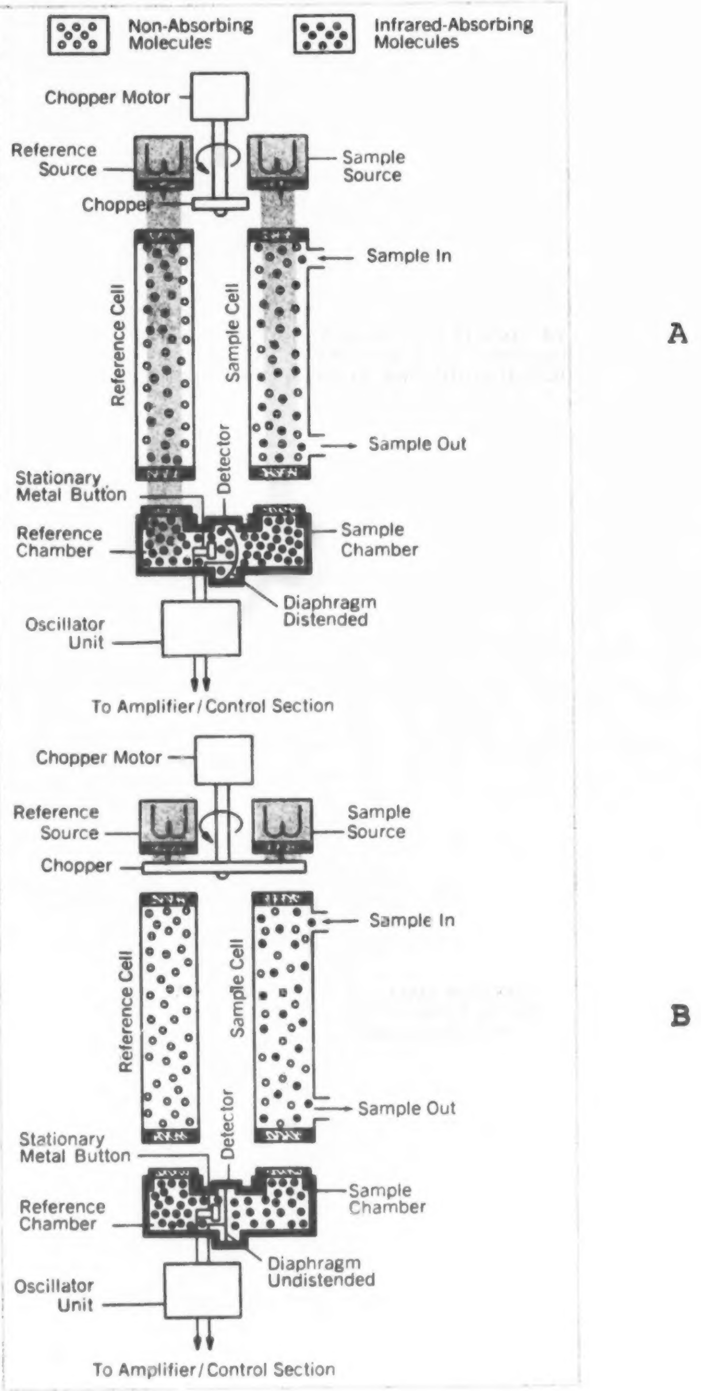
SHIPPING WEIGHT:

IR315S, 115 pounds; IR315L, 170 pounds.

NET WEIGHT:

IR315S, 85 pounds; IR315L, 120 pounds.

CATALOG NUMBERS:
95700 Model IR315S Infrared Analyzer (Short Path)
95701 Model IR315L Infrared Analyzer (Long Path)


Non-Absorbing Molecules
Infrared-Absorbing Molecules
Chopper Motor
Reference Source
Sample Source
Chopper
Sample In
Reference Cell
Sample Cell
A
Sample Out
Stationary Metal Button
Detector
Reference Chamber
Sample Chamber
Diaphragm Distended
Oscillator Unit
To Amplifier/Control Section
Chopper Motor
Reference Source
Sample Source
Chopper
Sample In
Reference Cell
Sample Cell
B
Sample Out
Stationary Metal Button
Detector
Reference Chamber
Sample Chamber
Diaphragm Undistended
Oscillator Unit
To Amplifier/Control Section

NON-DISPERSIVE INFRA-RED
ANALYZER SECTION SPECIFICATIONS
AND FUNCTIONAL DIAGRAM

FIGURE A-8

(1) Radiant energy absorption: In the sample cell through which the infrared radiation passes on the way to the sample chamber of the detector, part of the original energy of the sample infrared beam is absorbed by the component of interest present in the sample. In the reference cell, however, absorption of infrared energy from the reference beam is negligible, and the energy of this reference beam is higher.

(2) Temperature effect: Inside the detector, each beam heats the gas in the corresponding chamber, because of absorption of infrared energy by the component of interest. The gas in the reference chamber is heated to a higher temperature, however, since the energy available from the reference beam is higher.

(3) Pressure effect: The higher gas temperature in the reference chamber raises the pressure of this compartment above that of the sample chamber.

(4) Mechanical energy effect: The higher gas pressure in the reference chamber distends the diaphragm toward the sample chamber. The energy difference between the two chambers in thus expended in flexing the diaphragm.

(5) Capacitance effect: The diaphragm and an adjacent stationary metal button (see Figure A-8) constitute a two-plate variable capacitor. Distention of the diaphragm away from the button decreases the capacitance.

When the chopper blocks the beams, as in B of Figure A-8, pressures in the two chambers equalize, and the diaphragm returns to the undistended condition. As the chopper alternately blocks and unblocks the beams, therefore, the diaphragm pulses, thus changing detector capacitance cyclically. The detector signal is passed through the electronic circuitry, where it is treated and sent to a meter and recorder.

The meter reading is a function of the concentration of the component of interest in the sample stream. When the instrument is put into operation, it is adjusted so that a reading of zero or any desired arbitrary reading corresponds to a concentration of zero percent of the component of interest, while a fullscale reading corresponds to the highest concentration in the operating range covered. Each instrument is provided with a calibration curve for converting meter readings to concentrations.

APPENDIX B

EMISSIONS PERFORMANCE DATA REDUCTION PRINTOUT

GROUP 1

AIRCRAFT PROPULSION ENGINES

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                                                EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
                                                ********************************************

ENGINE   TFE 731-2        S/N    7305-2   DATE OF TEST    6/10/71    TYPE OF FUEL AV.KEROS.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED THRUST= 2800.0 RATED EGT=1700.0 DEG.F    RATED SPEED= 21000.0
DEW PT.= 30.0     REL.HUMIDITY= 10.0 PERCENT      SPECIFIC HUMIDITY=  .00359     BAROMETRIC PRESSURE=28.55 IN HGA
                                GND IDLE  FLT IDLE
POWER SETTING NUMBER                   1         2         6        11        16        20
PERCENT MAX. THRUST                  6.9      14.5      37.3      58.5      79.4      93.0
DELTA CORRECTED THRUST,LB.         202.3     425.5    1095.1    1715.6    2328.6    2730.0
MEASURED THRUST, LB.               193.0     406.0    1045.0    1637.0    2222.0    2605.0
EXHAUST GAS TEMP., DEG.F           854.0     945.0    1171.0    1329.0    1461.0    1537.0
SHAFT SPEED, N1, RPM              5760.0    8470.0   13040.0   15710.0   17650.0   18560.0
SHAFT SPEED, N2, RPM             14800.0   21070.0   25370.0   27020.0   27960.0   28430.0
COMPRESSOR INLET TEMP.,DEG.F        91.0      89.0      92.0      92.0      91.0      91.0
COMPRESSOR DSCHG. PRES.,PSIA        26.3      38.8      71.5      95.5     131.5     148.5
COMPRESSOR MAP FLOW,LB/SEC          4.87      7.58     14.21     19.08     23.79     26.60
FA RATIO BASED ON MAP FLOW         .0109     .0113     .0124     .0135     .0145     .0150
CORRECTED FUEL FLOW , LB/HR        177.0     285.0     587.0     858.0    1150.0    1330.0
FA RATIO CALC. FROM EMISSION       .0102     .0109     .0128     .0140     .0144     .0149
EQUIVALENCE RATIO                   .150      .159      .187      .205      .210      .217
*********************************************************SUMMARY OF REDUCED EMISSION DATA******************************************
CARBON DIOXIDE

    PERCENT BY VOLUME               2.03      2.20      2.60      2.86      2.93      3.03
    LB. CO2 PER LB. OF FUEL         3.05      3.10      3.13      3.15      3.15      3.15
    WEIGHT FLOW, LB./HR.           539.2     884.9    1838.8    2699.6    3622.4    4191.4

CARBON MONOXIDE

    PPM BY VOLUME                  463.4     263.6     149.3      65.5      37.7      24.7
    LB. PER 1000 LB. OF FUEL      44.212    23.589    11.469     4.585     2.579     1.630
    WEIGHT FLOW, LB./HR.           7.826     6.751     6.732     3.934     2.965     2.168

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                  253.8      84.7      28.9       3.9       1.2        .8
    LB. PER 1000 LB. OF FUEL      13.842     4.351     1.268      .155      .048      .031
    WEIGHT FLOW, LB./HR.           2.450     1.240      .744      .133      .056      .042

NITRIC OXIDE

    PPM BY VOLUME                    6.2      14.5      34.5      58.0      84.6     110.3
    LB. PER 1000 LB. OF FUEL        .630     1.397     2.840     4.349     6.197     7.813
    WEIGHT FLOW, LB./HR.            .112      .398     1.667     3.731     7.126    10.391

NITROGEN DIOXIDE

    PPM BY VOLUME                    7.7       6.5       8.0       6.8       5.8       6.2
    LB. PER 1000 LB. OF FUEL       1.204      .965     1.014      .778      .647      .674
    WEIGHT FLOW, LB./HR.            .213      .275      .595      .667      .744      .897

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                   13.9      21.1      42.6      64.8      90.4     116.5
    LB. PER 1000 LB. OF FUEL       2.171     3.108     5.368     7.445    10.147    12.653
    WEIGHT FLOW, LB./HR.            .384      .886     3.151     6.388    11.670    16.828

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
```

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                                        EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
                                        ********************************************
ENGINE     TSE231-1       S/N   2301-10    DATE OF TEST    6/18/71   TYPE OF FUEL         JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877    RATED SHP=  474.0    RATED EGT=1090.0 DEG.F    RATED SPEED= 51000.0
DEW PT.= 42.0     REL.HUMIDITY= 14.0 PERCENT     SPECIFIC HUMIDITY=  .00589    BAROMETRIC PRESSURE=28.60 IN HGA
                                  GND IDLE   FLT IDLE
POWER SETTING NUMBER                  1          2          6          11          16          20
PERCENT MAX. CORRECTED POWER        0.0        0.0       15.1        33.2        44.2        54.1
CORRECTED SHAFT HP                  0.0        0.0       71.7       157.4       209.5       256.3
MEASURED SHAFT HP                   0.0        0.0       71.7       157.8       210.2       257.9
EXHAUST GAS TEMP., DEG.F          910.0      935.0      995.0      1070.0      1100.0      1120.0
SHAFT SPEED, N1, RPM            32001.0    37746.0    41936.0     45065.0     46517.0     47423.0
SHAFT SPEED, N2, RPM            33652.0    44982.0    45004.0     45011.0     44967.0     44946.0
COMPRESSOR INLET TEMP.,DEG.F      109.0      109.0      109.0       111.0       112.0       115.0
COMPRESSOR DSCHG. PRES.,PSIA       34.9       47.4       60.5        72.5        78.9        85.3
COMPRESSOR MAP FLOW,LB/SEC         1.61       2.20       2.72        3.13        3.35        3.52
FA RATIO BASED ON MAP FLOW        .0130      .0129      .0141       .0160       .0170       .0177
CORRECTED FUEL FLOW , LB/HR        68.5       93.5      125.6       164.4       186.5       203.5
FA RATIO CALC. FROM EMISSION      .0122      .0123      .0136       .0149       .0159       .0176
EQUIVALENCE RATIO                  .177       .178       .198        .217        .231        .256
***************************************************SUMMARY OF REDUCED EMISSION DATA*****************************
CARBON DIOXIDE

     PERCENT BY VOLUME             2.46       2.50       2.79        3.05        3.25        3.59
     LB. CO2 PER LB. OF FUEL       3.11       3.14       3.15        3.16        3.16        3.16
     WEIGHT FLOW, LB./HR.         213.1      293.9      396.0       519.1       589.2       643.0

CARBON MONOXIDE

     PPM BY VOLUME                345.0      161.0      104.1        75.7        62.7        61.4
     LB. PER 1000 LB. OF FUEL    27.758     12.874      7.485       4.984       3.873       3.439
     WEIGHT FLOW, LB./HR.         1.903      1.204       .940        .819        .722        .700

UNBURNED HYDROCARBONS AS PPM CARBON

     PPM BY VOLUME                 99.0       21.5       11.8         7.8         8.1         7.6
     LB. PER 1000 LB. OF FUEL     4.555       .984       .483        .294        .286        .242
     WEIGHT FLOW, LB./HR.          .312       .092       .061        .048        .053        .049

NITRIC OXIDE

     PPM BY VOLUME                 16.8       31.0       55.1        83.0       103.0       122.7
     LB. PER 1000 LB. OF FUEL     1.448      2.652      4.248       5.859       6.819       7.358
     WEIGHT FLOW, LB./HR.          .099       .248       .534        .963       1.272       1.497

NITROGEN DIOXIDE

     PPM BY VOLUME                 14.4       11.5       10.7         8.8         8.7        12.6 ]
     LB. PER 1000 LB. OF FUEL     1.905      1.513      1.269        .953        .887       1.158 ] ?
     WEIGHT FLOW, LB./HR.          .131       .141       .159        .157        .165        .236 ]

TOTAL OXIDES OF NITROGEN AS NO2  (3)

     PPM BY VOLUME                 31.2       42.5       65.9        91.8       111.7       135.3
     LB. PER 1000 LB. OF FUEL     4.124      5.580      7.782       9.935      11.342      12.439
     WEIGHT FLOW, LB./HR.          .283       .522       .977       1.634       2.116       2.531

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                  EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   TPE331-151G      S/N  P-91165     DATE OF TEST      6/1/71   TYPE OF FUEL  AV1A KERO

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED SHP= 665.0      RATED EGT=1060.0 DEG.F    RATED SPEED= 41730.0
DEW PT.= 25.0     REL.HUMIDITY= 10.0 PERCENT      SPECIFIC HUMIDITY=  .00285     BAROMETRIC PRESSURE=28.67 IN HGA
                                 GND IDLE  FLT IDLE
POWER SETTING NUMBER                  1         2         6        11        16        20
PERCENT MAX. CORRECTED POWER         .2        .5      26.1      55.2      72.8      91.2
CORRECTED SHAFT HP                  1.0       3.2     173.4     367.4     483.9     605.9
MEASURED SHAFT HP                   1.0       3.1     171.4     361.8     476.0     596.6
EXHAUST GAS TEMP., DEG.F          735.0     575.0     700.0     830.0     935.0    1050.0
SHAFT SPEED, N1, RPM            27150.0   41000.0   41730.0   41730.0   41730.0   41730.0
COMPRESSOR INLET TEMP.,DEG.F      102.0      92.0      92.0      88.0      87.0      88.0
COMPRESSOR DSCHG. PRES.,PSIA
COMPRESSOR MAP FLOW,LB/SEC         2.52      6.06      6.12      6.08      6.04      5.96
FA RATIO BASED ON MAP FLOW        .0090     .0068     .0098     .0130     .0151     .0181
CORRECTED FUEL FLOW , LB/HR        75.0     137.0     201.0     265.0     307.0     362.0
FA RATIO CALC. FROM EMISSION      .0089     .0072     .0101     .0127     .0148     .0170
EQUIVALENCE RATIO                  .130      .105      .148      .185      .216      .248
*********************************************SUMMARY OF REDUCED EMISSION DATA*********************************************
CARBON DIOXIDE

    PERCENT BY VOLUME              1.74      1.44      2.06      2.59      3.02      3.45
    LB. CO2 PER LB. OF FUEL        2.99      3.07      3.13      3.14      3.15      3.15
    WEIGHT FLOW, LB./HR.          224.4     420.8     628.7     832.8     966.7    1141.0

CARBON MONOXIDE

    PPM BY VOLUME                 387.9     247.3     135.7      81.9      41.6      16.4
    LB. PER 1000 LB. OF FUEL     42.567    33.663    13.105     6.333     2.767      .953
    WEIGHT FLOW, LB./HR.          3.193     4.612     2.634     1.678      .849      .345

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                 549.3     138.1      36.8      11.2       8.7       5.9
    LB. PER 1000 LB. OF FUEL     34.456    10.743     2.031      .496      .329      .197
    WEIGHT FLOW, LB./HR.          2.584     1.472      .408      .131      .101      .071

NITRIC OXIDE

    PPM BY VOLUME                   3.1       6.1      19.1      32.7      47.8      62.0
    LB. PER 1000 LB. OF FUEL       .363      .886     1.977     2.711     3.404     3.857
    WEIGHT FLOW, LB./HR.           .027      .121      .397      .719     1.045     1.396

NITROGEN DIOXIDE

    PPM BY VOLUME                   7.9]     13.8      13.1       9.1       6.3       4.5
    LB. PER 1000 LB. OF FUEL      1.423] ?  3.093     2.073     1.161      .691      .431
    WEIGHT FLOW, LB./HR.           .107]     .424      .417      .308      .212      .156

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                  11.0      19.9      32.2      41.9      54.2      66.5
    LB. PER 1000 LB. OF FUEL      1.979     4.452     5.104     5.318     5.910     6.345
    WEIGHT FLOW, LB./HR.           .148      .610     1.026     1.409     1.814     2.297

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                   EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   TPE331-151G      S/N    P91168    DATE OF TEST    4/30/71    TYPE OF FUEL  JP-5

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED SHP=  665.0    RATED EGT=1060.0 DEG.F    RATED SPEED= 41730.0
DEW PT.= 25.0     REL.HUMIDITY= 11.0 PERCENT     SPECIFIC HUMIDITY=  .00284    BAROMETRIC PRESSURE=28.75 IN HGA
                                 GND IDLE  FLT IDLE
POWER SETTING NUMBER                  1         2          6         11         16         20
PERCENT MAX. CORRECTED POWER         .6       1.4       24.2       48.3       72.4       90.6
CORRECTED SHAFT HP                  4.2       9.7      161.0      320.8      481.2      603.1
MEASURED SHAFT HP                   4.1       9.5      158.7      317.3      476.0      596.6
EXHAUST GAS TEMP., DEG.F          698.0     590.0      700.0      825.0      960.0     1080.0
SHAFT SPEED, N1, RPM            27200.0   41730.0    41730.0    41730.0    41730.0    41730.0
COMPRESSOR INLET TEMP.,DEG.F       92.0      85.0       86.0       90.0       90.0       90.0
COMPRESSOR DSCHG. PRES.,PSIA       40.5      94.4       98.1      102.2      105.6      107.9
COMPRESSOR MAP FLOW,LB/SEC         2.56      6.21       6.15       6.09       6.00       5.94
FA RATIO BASED ON MAP FLOW        .0089     .0072      .0095      .0125      .0157      .0185
CORRECTED FUEL FLOW , LB/HR        77.0     150.0      198.0      255.0      317.0      369.0
FA RATIO CALC. FROM EMISSION      .0086     .0071      .0092      .0116      .0154      .0179
EQUIVALENCE RATIO                  .125      .104       .134       .169       .225       .262
**********************************************SUMMARY OF REDUCED EMISSION DATA*********************************************
CARBON DIOXIDE

    PERCENT BY VOLUME              1.62      1.44       1.87       2.37       3.14       3.64
    LB. CO2 PER LB. OF FUEL        2.90      3.11       3.13       3.14       3.15       3.15
    WEIGHT FLOW, LB./HR.          223.3     466.1      619.0      800.6      998.2     1162.7

CARBON MONOXIDE

    PPM BY VOLUME                 380.8     162.0      140.5      103.7       50.0       34.8
    LB. PER 1000 LB. OF FUEL     43.324    22.219     14.937      8.753      3.195      1.916
    WEIGHT FLOW, LB./HR.          3.336     3.333      2.958      2.232      1.013       .707

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                1037.4      53.6       26.2        6.1        3.0        1.3
    LB. PER 1000 LB. OF FUEL     67.464     4.198      1.591       .296       .111       .040
    WEIGHT FLOW, LB./HR.          5.195      .630       .315       .075       .035       .015

NITRIC OXIDE

    PPM BY VOLUME                   4.4      14.9       30.9       49.9       88.3      111.8
    LB. PER 1000 LB. OF FUEL       .533     2.189      3.517      4.513      6.046      6.593
    WEIGHT FLOW, LB./HR.           .041      .328       .696      1.151      1.917      2.433

NITROGEN DIOXIDE

    PPM BY VOLUME                  12.2      20.8       21.1       21.0       10.8        7.4
    LB. PER 1000 LB. OF FUEL      2.289     4.696      3.682      2.917      1.133       .670
    WEIGHT FLOW, LB./HR.           .176      .704       .729       .744       .359       .247

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                  16.6      35.7       52.0       70.9       99.1      119.2
    LB. PER 1000 LB. OF FUEL      3.106     8.052      9.075      9.836     10.403     10.778
    WEIGHT FLOW, LB./HR.           .239     1.208      1.797      2.508      3.298      3.977

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                   EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   TPE331-43A        S/N   P-61157    DATE OF TEST     5/11/71    TYPE OF FUEL         JP5

FUEL H/C=1.877     STOICHIOMETRIC F/A=  .06877     RATED SHP=  575.0    RATED EGT=1060.0 DEG.F    RATED SPEED= 41730.0
DEW PT.= 35.0      REL.HUMIDITY= 16.0 PERCENT      SPECIFIC HUMIDITY=  .00441      BAROMETRIC PRESSURE=28.76 IN HGA
                                  GND IDLE   FLT IDLE
POWER SETTING NUMBER                  1          2          6          11          16          20
PERCENT MAX. CORRECTED POWER         .5        1.1       24.5        46.8        69.2        87.6
CORRECTED SHAFT HP                  2.7        6.4      141.1       269.4       397.7       503.5
MEASURED SHAFT HP                   2.7        6.3      139.6       266.6       393.5       498.2
EXHAUST GAS TEMP., DEG.F          615.0      620.0      745.0       860.0       975.0      1090.0
SHAFT SPEED, N1, RPM            35535.0    41730.0    41730.0     41730.0     41730.0     41730.0
COMPRESSOR INLET TEMP.,DEG.F       96.0       88.0       90.0        90.0        90.0        90.0
COMPRESSOR DSCHG. PRES.,PSIA       66.4       95.4       98.9       102.1       104.3       106.0
CORRECTED FUEL FLOW , LB/HR       101.0      150.0      197.0       246.0       293.0       338.0
FA RATIO CALC. FROM EMISSION      .0078      .0079      .0104       .0127       .0143       .0166
EQUIVALENCE RATIO                  .113       .115       .152        .184        .208        .241
***************************************************SUMMARY OF REDUCED EMISSION DATA**************************************
CARBON DIOXIDE

    PERCENT BY VOLUME              1.54       1.62       2.14        2.60        2.93        3.40
    LB. CO2 PER LB. OF FUEL        3.04       3.14       3.15        3.16        3.16        3.16
    WEIGHT FLOW, LB./HR.          306.7      470.5      619.7       776.6       926.6      1069.5

CARBON MONOXIDE

    PPM BY VOLUME                 289.6      125.3      125.4        70.5        27.2        13.6
    LB. PER 1000 LB. OF FUEL     36.236     15.464     11.755       5.450       1.866        .806
    WEIGHT FLOW, LB./HR.          3.660      2.320      2.316       1.341        .547        .272

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                 369.0       24.5       12.0         2.7         2.1         1.6
    LB. PER 1000 LB. OF FUEL     26.392      1.727       .644        .121        .082        .053
    WEIGHT FLOW, LB./HR.          2.666       .259       .127        .030        .024        .018

NITRIC OXIDE

    PPM BY VOLUME                   4.6       21.3       37.8        69.7        97.3       119.1
    LB. PER 1000 LB. OF FUEL       .610      2.818      3.792       5.772       7.160       7.570
    WEIGHT FLOW, LB./HR.           .062       .423       .747       1.420       2.098       2.559

NITROGEN DIOXIDE

    PPM BY VOLUME                  13.2       19.6       25.5        15.3         8.0         7.3
    LB. PER 1000 LB. OF FUEL      2.723      3.973      3.923       1.948        .908        .712
    WEIGHT FLOW, LB./HR.           .275       .596       .773        .479        .266        .241

TOTAL OXIDES OF NITROGEN AS NO2   (3)

    PPM BY VOLUME                  17.8       40.9       63.3        85.0       105.3       126.4
    LB. PER 1000 LB. OF FUEL      3.658      8.293      9.737      10.797      11.884      12.318
    WEIGHT FLOW, LB./HR.           .369      1.244      1.918       2.656       3.482       4.163

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                         EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE     T76-G-410        S/N    GE00790     DATE OF TEST      5/6/71    TYPE OF FUEL        JP5

FUEL H/C=1.877     STOICHIOMETRIC F/A=  .06877    RATED SHP=  720.0     RATED EGT=1060.0 DEG.F     RATED SPEED= 41730.0
DEW PT.= 45.0      REL.HUMIDITY= 42.0 PERCENT     SPECIFIC HUMIDITY=  .00661     BAROMETRIC PRESSURE=28.61 IN HGA
                                     GND IDLE  FLT IDLE
POWER SETTING NUMBER                    1          2          6         11         16         20
PERCENT MAX. CORRECTED POWER           .3       20.7       41.0       62.7       83.0       96.8
CORRECTED SHAFT HP                    2.2      149.3      295.4      451.3      597.4      696.9
MEASURED SHAFT HP                     2.1      142.8      282.4      431.6      571.2      666.4
EXHAUST GAS TEMP., DEG.F            623.0      622.0      708.0      815.0      930.0     1010.0
SHAFT SPEED, N1, RPM              27230.0    41730.0    41730.0    41730.0    41730.0    41730.0
COMPRESSOR INLET TEMP.,DEG.F         61.0       59.0       59.0       59.0       59.0       59.0
COMPRESSOR DSCHG. PRES.,PSIA
COMPRESSOR MAP FLOW,LB/SEC           2.68       6.50       6.47       6.45       6.38       6.33
FA RATIO BASED ON MAP FLOW          .0077      .0086      .0107      .0132      .0158      .0178
CORRECTED FUEL FLOW , LB/HR          71.0      192.0      238.0      293.0      347.0      387.0
FA RATIO CALC. FROM EMISSION        .0083      .0092      .0112      .0130      .0151      .0168
EQUIVALENCE RATIO                    .121       .133       .163       .189       .220       .244
****************************************************SUMMARY OF REDUCED EMISSION DATA**************************************
CARBON DIOXIDE

     PERCENT BY VOLUME               1.61       1.86       2.29       2.65       3.09       3.44
     LB. CO2 PER LB. OF FUEL         2.97       3.11       3.13       3.15       3.16       3.16
     WEIGHT FLOW, LB./HR.           211.0      597.7      745.9      922.0     1095.2     1223.7

CARBON MONOXIDE

     PPM BY VOLUME                  482.2      223.0      190.2      151.5       91.1       39.9
     LB. PER 1000 LB. OF FUEL      56.740     23.785     16.571     11.432      5.928      2.280
     WEIGHT FLOW, LB./HR.           4.029      4.567      3.944      3.349      2.057       .882

UNBURNED HYDROCARBONS AS PPM CARBON

     PPM BY VOLUME                  564.1       91.4       39.9        9.2        2.2        1.4
     LB. PER 1000 LB. OF FUEL      37.939      5.575      1.987       .396       .083       .048
     WEIGHT FLOW, LB./HR.           2.694      1.070       .473       .116       .029       .019

NITRIC OXIDE

     PPM BY VOLUME                    1.9       12.6       27.5       50.7       80.8       98.1
     LB. PER 1000 LB. OF FUEL        .240      1.444      2.566      4.099      5.630      6.155
     WEIGHT FLOW, LB./HR.            .017       .277       .611      1.201      1.954      2.382

NITROGEN DIOXIDE

     PPM BY VOLUME                   12.1       29.3       29.3       22.1       11.7        8.7
     LB. PER 1000 LB. OF FUEL       2.331      5.137      4.200      2.745      1.251       .839
     WEIGHT FLOW, LB./HR.            .166       .986      1.000       .804       .434       .325

TOTAL OXIDES OF NITROGEN AS NO2  (3)

     PPM BY VOLUME                   14.0       42.0       56.8       72.8       92.5      106.8
     LB. PER 1000 LB. OF FUEL       2.698      7.351      8.133      9.030      9.883     10.276
     WEIGHT FLOW, LB./HR.            .192      1.411      1.936      2.646      3.429      3.977

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

GROUP 2

SMALL AUXILIARY POWER UNITS

GT-8747-R

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                         EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE    GTCP30-92        S/N   P-28794     DATE OF TEST     5/17/71    TYPE OF FUEL AV.KEROS.
          (ATOMIZERS)
FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED SHP=   40.0    RATED EGT=1320.0 DEG.F    RATED SPEED= 59000.0
DEW PT.=  7.0     REL.HUMIDITY=  5.0 PERCENT     SPECIFIC HUMIDITY=  .00117    BAROMETRIC PRESSURE=28.56 IN HGA
                                                   SHP LOADING ONLY                              COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                       1         6        11        16        20 |      22        19        15        10         5
PERCENT MAX. CORRECTED POWER             0.0      25.8      51.3      77.2     102.8 |   102.5      76.8      51.3      25.6       0.0
CORRECTED SHAFT HP                       0.0      10.3      20.5      30.9      41.1 |    41.0      30.7      20.5      10.3       0.0
MEASURED SHAFT HP                        0.0      10.2      20.2      30.5      40.7 |    40.6      30.4      20.3      10.2       0.0
EXHAUST GAS TEMP., DEG.F               640.0     675.0     710.0     745.0     795.0 |  1318.0    1320.0    1320.0    1320.0    1320.0
SHAFT SPEED, N1, RPM                 59200.0   59200.0   59100.0   59100.0   59100.0 | 58900.0   58900.0   59000.0   59000.0   59000.0
COMPRESSOR INLET TEMP.,DEG.F            83.0      96.0     100.0      96.0      98.0 |    97.0      98.0      99.0      98.0      98.0
COMPRESSOR DSCHG. PRES.,PSIA            39.3      39.3      39.4      39.6      39.7 |    37.0      36.4      35.8      35.1      34.7
CORRECTED BLEED FLOW, LB/MIN            0.00      0.00      0.00      0.00      0.00 |   25.51     27.52     29.43     31.13     32.54
CORRECTED FUEL FLOW , LB/HR             35.4      37.4      40.4      43.4      47.4 |    69.0      69.0      67.5      65.5      64.0
FA RATIO CALC. FROM EMISSION           .0086     .0093     .0099     .0106     .0114 |   .0201     .0199     .0198     .0195     .0191
EQUIVALENCE RATIO                       .125      .136      .145      .154      .166 |    .294      .290      .289      .284      .280
***************************************************SUMMARY OF REDUCED EMISSION DATA*************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                   1.72      1.88      2.02      2.15      2.32 |    4.07      4.02      4.00      3.94      3.88
    LB. CO2 PER LB. OF FUEL             3.09      3.11      3.12      3.12      3.13 |    3.15      3.14      3.15      3.14      3.14
    WEIGHT FLOW, LB./HR.               109.2     116.2     125.9     135.6     148.4 |   217.0     217.0     212.3     205.9     201.2

CARBON MONOXIDE

    PPM BY VOLUME                      331.4     266.3     224.5     193.0     170.3 |   107.0     111.5     111.5     121.3     123.9
    LB. PER 1000 LB. OF FUEL          37.788    27.997    22.091    17.874    14.637 |   5.259     5.549     5.576     6.159     6.394
    WEIGHT FLOW, LB./HR.               1.338     1.047      .892      .776      .694 |    .363      .383      .376      .403      .409

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                       52.6      24.5      13.5       9.7       6.6 |     4.9       4.9       3.8       3.5       3.2
    LB. PER 1000 LB. OF FUEL           3.428     1.472      .761      .512      .326 |    .139      .139      .110      .103      .094
    WEIGHT FLOW, LB./HR.                .121      .055      .031      .022      .015 |    .010      .010      .007      .007      .006

NITRIC OXIDE

    PPM BY VOLUME                        7.7       9.2      11.3      14.0      16.3 |    41.8      40.4      39.2      37.6      36.0
    LB. PER 1000 LB. OF FUEL            .936     1.038     1.194     1.392     1.500 |   2.201     2.156     2.102     2.046     1.989
    WEIGHT FLOW, LB./HR.                .033      .039      .048      .060      .071 |    .152      .149      .142      .134      .127

NITROGEN DIOXIDE

    PPM BY VOLUME                        5.1       5.1       5.0       5.2       5.3 |     4.1       3.9       3.5       3.7       4.3
    LB. PER 1000 LB. OF FUEL            .948      .883      .802      .785      .750 |    .332      .315      .204      .309      .365
    WEIGHT FLOW, LB./HR.                .034      .033      .032      .034      .036 |    .023      .022      .019      .020      .023

TOTAL OXIDES OF NITROGEN AS NO2   (3)

    PPM BY VOLUME                       12.7      14.3      16.3      19.2      21.6 |    45.9      44.3      42.7      41.3      40.3
    LB. PER 1000 LB. OF FUEL           2.383     2.475     2.632     2.919     3.049 |   3.706     3.620     3.506     3.446     3.415
    WEIGHT FLOW, LB./HR.                .084      .093      .106      .127      .145 |    .256      .250      .237      .226      .219

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                    EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP30-92          S/N   P-28794     DATE OF TEST     5/18/71    TYPE OF FUEL AV.KEROS.
         (VAPORIZERS)                          RATED SHP=   40.0    RATED EGT=1320.0 DEG.F     RATED SPEED= 59000.0
FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843  SPECIFIC HUMIDITY=  .00202    BAROMETRIC PRESSURE=28.84 IN HGA
DEW PT.= 18.0     REL.HUMIDITY= 15.0 PERCENT                                     COMBINATION SHP/BLEED LOADING
                                              SHP LOADING ONLY
POWER SETTING NUMBER                  1        6        11        16        20   |    22        19        15        10         5
PERCENT MAX. CORRECTED POWER        0.0     25.8      51.6      77.2     102.4   |  101.7      76.2      50.6      25.3       0.0
CORRECTED SHAFT HP                  0.0     10.3      20.6      30.9      40.9   |   40.7      30.5      20.2      10.1       0.0
MEASURED SHAFT HP                   0.0     10.2      20.4      30.5      40.6   |   40.3      30.3      20.2      10.1       0.0
EXHAUST GAS TEMP., DEG.F          610.0    650.0     695.0     765.0     850.0   | 1315.0    1320.0    1320.0    1335.0    1330.0
SHAFT SPEED, N1, RPM            59200.0  59200.0   59200.0   59000.0   58900.0   |58600.0   58600.0   58600.0   58600.0   58600.0
COMPRESSOR INLET TEMP.,DEG.F       82.0     85.0      85.0      83.0      88.0   |   89.0      91.0      95.0      96.0      95.0
COMPRESSOR DSCHG. PRES.,PSIA       40.2     40.2      40.3      40.5      40.5   |   38.3      37.4      36.5      35.7      35.1
CORRECTED BLEED FLOW, LB/MIN       0.00     0.00      0.00      0.00      0.00   |  20.07     24.00     27.39     30.95     32.82
CORRECTED FUEL FLOW , LB/HR        36.4     39.4      42.4      46.4      50.3   |   68.0      68.0      67.0      67.0      66.0
FA RATIO CALC. FROM EMISSION      .0086    .0094     .0099     .0103     .0109   |  .0157     .0159     .0171     .0177     .0179
EQUIVALENCE RATIO                  .125     .137      .145      .150      .159   |   .229      .232      .249      .258      .261
****************************************SUMMARY OF REDUCED EMISSION DATA*****************************************************

CARBON DIOXIDE
   PERCENT BY VOLUME               1.74     1.90      2.01      2.08      2.20   |   3.17      3.21      3.44      3.56      3.60
   LB. CO2 PER LB. OF FUEL         3.11     3.11      3.11      3.11      3.11   |   3.12      3.12      3.12      3.12      3.12
   WEIGHT FLOW, LB./HR.           113.2    122.6     131.9     144.2     156.2   |  212.2     212.2     209.2     209.3     206.2

CARBON MONOXIDE
   PPM BY VOLUME                  234.5    257.1     271.4     309.5     332.8   |  341.2     345.4     342.3     346.8     341.1
   LB. PER 1000 LB. OF FUEL      26.657   26.759    26.750    29.482    29.876   | 21.380    21.366    19.773    19.349    18.831
   WEIGHT FLOW, LB./HR.            .970    1.054     1.134     1.368     1.503   |  1.[illegible]4     1.453     1.325     1.296     1.243

UNBURNED HYDROCARBONS AS PPM CARBON
   PPM BY VOLUME                    7.3      5.3       5.6       7.1       6.5   |    3.1       2.6       1.8       1.5       1.0
   LB. PER 1000 LB. OF FUEL        .475     .312      .315      .384      .336   |   .110      .091      .060      .048      .032
   WEIGHT FLOW, LB./HR.            .017     .012      .013      .018      .017   |   .008      .006      .004      .003      .002

NITRIC OXIDE
   PPM BY VOLUME                   12.0     13.1      14.0      15.9      16.6   |   28.9      29.5      31.6      34.5      35.3
   LB. PER 1000 LB. OF FUEL       1.460    1.466     1.483     1.623     1.597   |  1.943     1.958     1.953     2.060     2.086
   WEIGHT FLOW, LB./HR.            .053     .058      .063      .075      .080   |   .132      .133      .131      .138      .138

NITROGEN DIOXIDE
   PPM BY VOLUME                    7.2      7.6       8.0       8.6       9.6   |    9.9       9.2       8.9       9.3       9.4
   LB. PER 1000 LB. OF FUEL       1.349    1.304     1.300     1.350     1.420   |  1.017      .933      .847      .851      .851
   WEIGHT FLOW, LB./HR.            .049     .051      .055      .063      .071   |   .069      .063      .057      .057      .056

TOTAL OXIDES OF NITROGEN AS NO2  (3)
   PPM BY VOLUME                   19.2     20.8      22.1      24.5      26.2   |   38.8      38.7      40.5      43.7      44.7
   LB. PER 1000 LB. OF FUEL       3.587    3.551     3.574     3.839     3.869   |  3.996     3.935     3.842     4.009     4.049
   WEIGHT FLOW, LB./HR.            .131     .140      .152      .178      .195   |   .272      .268      .257      .249      .267

***** NOTES *****
   1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
   2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
   3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                          EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP36-6          S/N   P-34696     DATE OF TEST     5/14/71    TYPE OF FUEL          JP5

FUEL H/C=1.877     STOICHIOMETRIC F/A=  .06877     RATED SHP=  160.0    RATED EGT=1200.0 DEG.F    RATED SPEED= 58608.0
DEW PT.= 38.0      REL.HUMIDITY= 14.0 PERCENT      SPECIFIC HUMIDITY=  .00502    BAROMETRIC PRESSURE=28.65 IN HGA
                                        SHP LOADING ONLY              COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                   1          6          11    |     15         10          5
PERCENT MAX. CORRECTED POWER          0.0       25.8        33.8   |    57.2       25.5        0.0
CORRECTED SHAFT HP                    0.0       41.3        54.1   |    91.6       40.8        0.0
MEASURED SHAFT HP                     0.0       41.0        53.7   |    91.1       40.6        0.0
EXHAUST GAS TEMP., DEG.F            600.0      715.0       750.0   |  1200.0     1195.0     1175.0
SHAFT SPEED, N1, RPM              59200.0    59100.0     59000.0   | 58400.0    58600.0    58800.0
COMPRESSOR INLET TEMP.,DEG.F         98.0       98.0        98.0   |   100.0      101.0      102.0
COMPRESSOR DSCHG. PRES.,PSIA         53.0       53.2        53.2   |    50.1       47.0       44.3
CORRECTED BLEED FLOW, LB/MIN         0.00       0.00        0.00   |   42.35      59.04      81.70
CORRECTED FUEL FLOW , LB/HR          64.5       68.3        94.1   |   149.4      137.0      123.9
FA RATIO CALC. FROM EMISSION        .0074      .0096       .0104   |   .0187      .0176      .0180
EQUIVALENCE RATIO                    .108       .140        .151   |    .271       .257       .262
******************************************************SUMMARY OF REDUCED EMISSION DATA*************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                1.52       1.96        2.12   |    3.79       3.58       3.65
    LB. CO2 PER LB. OF FUEL          3.13       3.13        3.13   |    3.15       3.14       3.14
    WEIGHT FLOW, LB./HR.            202.1      213.8       294.6   |   469.9      430.1      389.4

CARBON MONOXIDE

    PPM BY VOLUME                   145.6      206.5       218.8   |   243.3      291.9      259.0
    LB. PER 1000 LB. OF FUEL       19.069     20.957      20.573   |  12.857     16.296     14.193
    WEIGHT FLOW, LB./HR.            1.230      1.431       1.935   |   1.921      2.233      1.758

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                    14.2       15.2        14.6   |     3.9        7.2        9.0
    LB. PER 1000 LB. OF FUEL        1.064       .879        .785   |    .119       .230       .281
    WEIGHT FLOW, LB./HR.             .069       .060        .074   |    .018       .031       .035

NITRIC OXIDE

    PPM BY VOLUME                    11.3       18.9        20.2   |    47.5       40.9       41.3
    LB. PER 1000 LB. OF FUEL        1.591      2.056       2.036   |   2.689      2.446      2.425
    WEIGHT FLOW, LB./HR.             .103       .140        .192   |    .402       .335       .300

NITROGEN DIOXIDE

    PPM BY VOLUME                     6.8       10.3        12.1   |    12.2       13.4       12.6
    LB. PER 1000 LB. OF FUEL        1.455      1.715       1.868   |   1.055      1.230      1.135
    WEIGHT FLOW, LB./HR.             .094       .117        .176   |    .158       .169       .141

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                    18.1       29.2        32.3   |    59.7       54.3       53.9
    LB. PER 1000 LB. OF FUEL        3.895      4.867       4.990   |   5.178      4.980      4.852
    WEIGHT FLOW, LB./HR.             .251       .332        .469   |    .774       .682       .601

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                         EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP36-6          S/N   P-34772    DATE OF TEST    5/14/71   TYPE OF FUEL        JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877    RATED SHP=  160.0    RATED EGT=1200.0 DEG.F    RATED SPEED= 58608.0
DEW PT.= 37.0     REL.HUMIDITY= 17.0 PERCENT     SPECIFIC HUMIDITY=  .00481    BAROMETRIC PRESSURE=28.70 IN HGA
                                                  SHP LOADING ONLY                    COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                   1         6        11        16        20  |      15        10         5
PERCENT MAX. CORRECTED POWER         0.0      25.1      49.9      72.2      75.1  |    49.3      24.7       0.0
CORRECTED SHAFT HP                   0.0      40.2      79.8     115.6     120.2  |    78.9      39.5       0.0
MEASURED SHAFT HP                    0.0      39.5      78.7     114.0     118.7  |    78.2      39.1       0.0
EXHAUST GAS TEMP., DEG.F           540.0     635.0     740.0     860.0     905.0  |  1145.0    1195.0    1155.0
SHAFT SPEED, N1, RPM             59100.0   58900.0   58600.0   58500.0   58300.0  | 58200.0   58300.0   58500.0
COMPRESSOR INLET TEMP.,DEG.F        84.0      86.0      88.0      89.0      90.0  |    93.0      94.0      93.0
COMPRESSOR DSCHG. PRES.,PSIA        52.9      53.4      54.4      54.4      54.1  |    50.1      47.3      44.3
CORRECTED BLEED FLOW, LB/MIN        0.00      0.00      0.00      0.00      0.00  |   49.16     64.60     74.28
CORRECTED FUEL FLOW , LB/HR         72.6      90.6     109.6     128.7     132.9  |   139.8     132.9     122.7
FA RATIO CALC. FROM EMISSION       .0080     .0101     .0122     .0143     .0150  |   .0187     .0170     .0176
EQUIVALENCE RATIO                   .116      .146      .178      .208      .219  |    .271      .247      .256
**********************************************SUMMARY OF REDUCED EMISSION DATA*******************************************
CARBON DIOXIDE

   PERCENT BY VOLUME                1.63      2.06      2.50      2.93      3.07  |    3.80      3.47      3.59
   LB. CO2 PER LB. OF FUEL          3.14      3.15      3.15      3.15      3.15  |    3.16      3.16      3.16
   WEIGHT FLOW, LB./HR.            228.2     285.0     345.1     405.7     418.9  |   441.2     419.4     387.3

CARBON MONOXIDE

   PPM BY VOLUME                   114.1     130.1     130.7     122.8     120.2  |   116.9     100.0     106.9
   LB. PER 1000 LB. OF FUEL       13.969    12.628    10.465     8.411     7.851  |   6.175     5.791     5.988
   WEIGHT FLOW, LB./HR.            1.014     1.144     1.147     1.082     1.043  |    .863      .769      .735

UNBURNED HYDROCARBONS AS PPM CARBON

   PPM BY VOLUME                     3.5       1.8       1.4        .5        .3  |      .4        .6        .5
   LB. PER 1000 LB. OF FUEL         .245      .100      .066      .021      .010  |    .011      .019      .015
   WEIGHT FLOW, LB./HR.             .018      .009      .007      .003      .001  |    .001      .002      .002

NITRIC OXIDE

   PPM BY VOLUME                    16.0      21.1      27.4      37.6      41.4  |    47.4      54.7      50.5
   LB. PER 1000 LB. OF FUEL        2.102     2.192     2.348     2.762     2.896  |   2.685     3.393     3.028
   WEIGHT FLOW, LB./HR.             .153      .199      .257      .355      .385  |    .375      .451      .372

NITROGEN DIOXIDE

   PPM BY VOLUME                     5.2       8.1       9.7       9.2       8.7  |     7.3       6.9       6.3
   LB. PER 1000 LB. OF FUEL        1.054     1.294     1.279     1.032      .930  |    .634      .652      .580
   WEIGHT FLOW, LB./HR.             .077      .117      .140      .133      .124  |    .089      .087      .071

TOTAL OXIDES OF NITROGEN AS NO2  (3)

   PPM BY VOLUME                    21.3      29.2      37.1      46.8      50.0  |    54.7      61.5      56.8
   LB. PER 1000 LB. OF FUEL        4.276     4.654     4.879     5.267     5.369  |   4.751     5.853     5.222
   WEIGHT FLOW, LB./HR.             .310      .422      .535      .678      .713  |    .664      .778      .641

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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GROUP 3

MEDIUM-SIZE AUXILIARY POWER UNITS

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                                              EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-180        S/N      P-567    DATE OF TEST     6/14/71    TYPE OF FUEL AV.KEROS.

FUEL H/C=1.928     STOICHIOMETRIC F/A=  .06843    RATED SHP=  160.0    RATED EGT=1150.0 DEG.F     RATED SPEED= 40700.0
DEW PT.= 38.0      REL.HUMIDITY= 12.0 PERCENT     SPECIFIC HUMIDITY=  .00501     BAROMETRIC PRESSURE=28.70 IN HGA
                                                  SHP LOADING ONLY                            COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                   1         6        11        16        20  |      22        19        15        10         5
PERCENT MAX. CORRECTED POWER         0.0      25.0      49.1      73.2      96.8  |    96.3      71.9      48.4      24.3       0.0
CORRECTED SHAFT HP                   0.0      40.1      78.6     117.2     154.9  |   154.1     115.0      77.4      38.8       0.0
MEASURED SHAFT HP                    0.0      39.9      78.5     116.9     154.9  |   154.5     115.6      77.9      39.0       0.0
EXHAUST GAS TEMP., DEG.F           515.0     585.0     655.0     730.0     815.0  |  1150.0    1150.0    1150.0    1150.0    1150.0
SHAFT SPEED, N1, RPM             41700.0   41600.0   41400.0   41300.0   41100.0  | 41000.0   41000.0   41100.0   41200.0   41200.0
COMPRESSOR INLET TEMP.,DEG.F        95.0     100.0     102.0     102.0     104.0  |   107.0     110.0     111.0     110.0     114.0
COMPRESSOR DSCHG. PRES.,PSIA        55.6      55.1      54.8      54.4      53.6  |    50.0      49.0      47.5      46.0      44.1
CORRECTED BLEED FLOW, LB/MIN        0.00      0.00      0.00      0.00      0.00  |   66.12     86.54    100.31    115.77    132.81
CORRECTED FUEL FLOW , LB/HR        122.8     137.0     155.0     177.0     207.0  |   279.5     272.5     262.5     251.5     241.5
FA RATIO CALC. FROM EMISSION       .0069     .0079     .0091     .0105     .0119  |   .0168     .0157     .0156     .0162     .0167
EQUIVALENCE RATIO                   .102      .116      .133      .153      .174  |    .245      .229      .228      .236      .244
***********************************************SUMMARY OF REDUCED EMISSION DATA*************************************************
CARBON DIOXIDE

     PERCENT BY VOLUME              1.41      1.62      1.85      2.13      2.42  |    3.40      3.17      3.16      3.27      3.38
     LB. CO2 PER LB. OF FUEL        3.12      3.12      3.12      3.12      3.12  |    3.13      3.13      3.13      3.13      3.13
     WEIGHT FLOW, LB./HR.          382.6     427.2     483.6     552.6     645.9  |   875.6     852.5     820.5     786.8     756.0

CARBON MONOXIDE

     PPM BY VOLUME                 146.8     160.9     180.8     200.2     235.7  |   222.9     252.1     277.9     261.8     248.4
     LB. PER 1000 LB. OF FUEL     20.582    19.739    19.367    18.721    19.382  |  13.088    15.832    17.483    15.926    14.627
     WEIGHT FLOW, LB./HR.          2.527     2.704     3.002     3.314     4.012  |   3.658     4.314     4.589     4.005     3.532

UNBURNED HYDROCARBONS AS PPM CARBON

     PPM BY VOLUME                  26.3      24.7      20.8      18.2      27.3  |     6.8       7.6       8.5       6.6       5.6
     LB. PER 1000 LB. OF FUEL      2.104     1.729     1.274      .975     1.284  |    .228      .271      .307      .231      .190
     WEIGHT FLOW, LB./HR.           .258      .237      .198      .173      .266  |    .064      .074      .081      .058      .046

NITRIC OXIDE

     PPM BY VOLUME                  12.0      14.4      28.1      22.0      26.5  |    44.7      40.3      37.3      42.1      44.6
     LB. PER 1000 LB. OF FUEL      1.804     1.900     3.229     2.208     2.333  |   2.811     2.712     2.516     2.743     2.817
     WEIGHT FLOW, LB./HR.           .222      .260      .501      .391      .483  |    .786      .739      .661      .690      .680

NITROGEN DIOXIDE

     PPM BY VOLUME                   6.7       8.2        .4      10.4      11.6  |    10.5      11.8      13.8      11.9      10.9
     LB. PER 1000 LB. OF FUEL      1.542     1.654      .066     1.597     1.562  |   1.009     1.220     1.422     1.190     1.050
     WEIGHT FLOW, LB./HR.           .189      .227      .010      .283      .323  |    .282      .333      .373      .299      .253

TOTAL OXIDES OF NITROGEN AS NO2  (3)

     PPM BY VOLUME                  18.7      22.7      28.5      32.4      38.0  |    55.1      52.1      51.1      54.0      55.5
     LB. PER 1000 LB. OF FUEL      4.307     4.567     5.016     4.982     5.138  |   5.318     5.379     5.280     5.396     5.368
     WEIGHT FLOW, LB./HR.           .529      .626      .778      .882     1.064  |   1.486     1.466     1.386     1.357     1.296

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2.CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                     EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-180        S/N     P-507    DATE OF TEST   6/14/71   TYPE OF FUEL AVIA.KERO.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843     RATED SHP=  160.0    RATED EGT=1150.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 39.0     REL.HUMIDITY= 12.0 PERCENT      SPECIFIC HUMIDITY=  .00524    BAROMETRIC PRESSURE=28.58 IN HGA
                                                 SHP LOADING ONLY                             COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                        1         6         11        16        20  |     22        19        15        10         5
PERCENT MAX. CORRECTED POWER              0.0      24.9       49.6      74.9      99.1  |   98.0      73.8      48.4      24.3       0.0
CORRECTED SHAFT HP                        0.0      39.7       79.3     119.9     159.5  |  156.8     118.0      77.5      38.9       0.0
MEASURED SHAFT HP                         0.0      39.5       79.0     119.3     157.8  |  156.3     117.8      77.4      38.9       0.0
EXHAUST GAS TEMP., DEG.F                510.0     580.0      645.0     710.0     790.0  | 1150.0    1150.0    1150.0    1150.0    1150.0
SHAFT SPEED, N1, RPM                  41700.0   41400.0    41400.0   41100.0   41000.0  |40600.0   40600.0   40600.0   40700.0   40800.0
COMPRESSOR INLET TEMP.,DEG.F            105.0     104.0      104.0     104.0     104.0  |  105.0     107.0     108.0     108.0     107.0
COMPRESSOR DSCHG. PRES.,PSIA             54.2      53.2       53.2      53.3      53.3  |   49.7      48.6      46.9      45.6      43.7
CORRECTED BLEED FLOW, LB/MIN             0.00      0.00       0.00      0.00      0.00  |  70.08     89.54    107.18    124.04    137.74
CORRECTED FUEL FLOW , LB/HR             116.0     134.0      153.0     175.0     194.0  |  271.5     271.5     260.5     252"5     235.0
FA RATIO CALC. FROM EMISSION            .0065     .0077      .0087     .0102     .0116  |  .0164     .0163     .0162     .0165     .0169
EQUIVALENCE RATIO                        .095      .112       .127      .149      .169  |   .240      .238      .237      .241      .247
*************************************************SUMMARY OF REDUCED EMISSION DATA*******************************************************
CARBON DIOXIDE

     PERCENT BY VOLUME                   1.33      1.56       1.78      2.07      2.35  |   3.34      3.30      3.29      3.34      3.43
     LB. CO2 PER LB. OF FUEL             3.12      3.13       3.13      3.13      3.13  |   3.14      3.14      3.14      3.14      3.14
     WEIGHT FLOW, LB./HR.               362.0     418.9      478.5     547.7     607.1  |  851.9     851.3     816.7     791.6     737.0

CARBON MONOXIDE

     PPM BY VOLUME                      125.3     128.1      140.4     152.8     177.3  |  174.3     194.5     194.6     198.7     193.1
     LB. PER 1000 LB. OF FUEL          18.699    16.298     15.716    14.680    15.007  | 10.433    11.748    11.812    11.874    11.240
     WEIGHT FLOW, LB./HR.               2.169     2.184      2.405     2.569     2.911  |  2.833     3.189     3.077     2.998     2.641

UNBURNED HYDROCARBONS AS PPM CARBON

     PPM BY VOLUME                       16.9      12.4       11.5       8.7       7.1  |    1.0       2.1       2.5       2.2       2.0
     LB. PER 1000 LB. OF FUEL           1.443      .902       .735      .476      .341  |   .033      .074      .088      .076      .066
     WEIGHT FLOW, LB./HR.                .167      .121       .112      .083      .066  |   .009      .020      .023      .019      .016

NITRIC OXIDE

     PPM BY VOLUME                       11.4      14.9       17.7      22.4      27.2  |   44.4      43.5      41.7      43.0      43.2
     LB. PER 1000 LB. OF FUEL           1.820     2.034      2.119     2.301     2.466  |  2.847     2.818     2.711     2.752     2.695
     WEIGHT FLOW, LB./HR.                .211      .273       .324      .403      .478  |   .773      .765      .706      .695      .633

NITROGEN DIOXIDE

     PPM BY VOLUME                        5.9       7.3        8.5      10.3      10.9  |   10.0       9.4      10.0       9.1       9.5
     LB. PER 1000 LB. OF FUEL           1.457     1.524      1.569     1.620     1.510  |   .979      .934      .998      .889      .910
     WEIGHT FLOW, LB./HR.                .169      .204       .240      .284      .293  |   .266      .254      .260      .224      .214

TOTAL OXIDES OF NITROGEN AS NO2  (3)

     PPM BY VOLUME                       17.3      22.2       26.2      32.6      38.1  |   54.4      53.0      51.7      52.1      52.7
     LB. PER 1000 LB. OF FUEL           4.247     4.642      4.818     5.148     5.291  |  5.344     5.255     5.154     5.109     5.041
     WEIGHT FLOW, LB./HR.                .493      .622       .737      .901     1.027  |  1.451     1.427     1.343     1.290     1.185

***** NOTES *****
      1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
      2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
      3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                        EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-180        S/N     P-518    DATE OF TEST    6/15/71   TYPE OF FUEL AVIA.KERO.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED SHP=  160.0    RATED EGT=1150.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 36.0     REL.HUMIDITY= 13.0 PERCENT     SPECIFIC HUMIDITY=  .00462     BAROMETRIC PRESSURE=28.63 IN HGA
                                                 SHP LOADING ONLY                          COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                    1         6        11        16        20  |     22        19        15        10         5
PERCENT MAX. CORRECTED POWER          0.0      25.7      49.9      74.5      99.6  |   98.3      73.0      48.8      24.4       0.0
CORRECTED SHAFT HP                    0.0      41.2      79.9     119.2     159.4  |  157.3     116.8      78.1      39.0       0.0
MEASURED SHAFT HP                     0.0      40.8      79.3     118.3     158.3  |  156.8     117.2      78.3      39.1       0.0
EXHAUST GAS TEMP., DEG.F            490.0     565.0     635.0     710.0     805.0  | 1150.0    1150.0    1150.0    1150.0    1150.0
SHAFT SPEED, N1, RPM              41600.0   41500.0   41300.0   41100.0   41000.0  |40600.0   40700.0   40800.0   40800.0   40900.0
COMPRESSOR INLET TEMP.,DEG.F         96.0      96.0      98.0      98.0      99.0  |  103.0     110.0     110.0     110.0     110.0
COMPRESSOR DSCHG. PRES.,PSIA         54.8      54.6      53.9      53.5      53.0  |   49.8      49.0      47.7      46.4      44.7
CORRECTED BLEED FLOW, LB/MIN         0.00      0.00      0.00      0.00      0.00  |  73.35     88.73    104.08    120.55    135.61
CORRECTED FUEL FLOW , LB/HR         119.0     138.0     157.0     176.0     201.5  |  281.5     268.5     261.5     253.5     248.5
FA RATIO CALC. FROM EMISSION        .0068     .0079     .0092     .0104     .0122  |  .0183     .0169     .0166     .0170     .0173
EQUIVALENCE RATIO                    .100      .116      .135      .152      .179  |   .267      .247      .243      .248      .252
***************************************************SUMMARY OF REDUCED EMISSION DATA*********************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                1.39      1.61      1.87      2.10      2.47  |   3.70      3.41      3.36      3.42      3.48
    LB. CO2 PER LB. OF FUEL          3.12      3.11      3.11      3.11      3.11  |   3.14      3.13      3.13      3.12      3.13
    WEIGHT FLOW, LB./HR.            370.9     429.8     488.4     548.0     627.5  |  883.4     839.7     817.3     792.0     776.7

CARBON MONOXIDE

    PPM BY VOLUME                   160.8     199.0     255.3     266.1     311.5  |  187.2     282.9     298.2     314.6     309.4
    LB. PER 1000 LB. OF FUEL       22.908    24.449    26.981    25.057    24.984  | 10.117    16.496    17.642    18.273    17.667
    WEIGHT FLOW, LB./HR.            2.726     3.374     4.236     4.410     5.034  |  2.848     4.429     4.613     4.632     4.390

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                     4.0       5.1       6.3       5.3       4.3  |     .6       7.1       9.7      11.1       9.8
    LB. PER 1000 LB. OF FUEL         .323      .360      .383      .283      .199  |   .018      .237      .329      .368      .320
    WEIGHT FLOW, LB./HR.             .038      .050      .060      .050      .040  |   .005      .064      .086      .093      .080

NITRIC OXIDE

    PPM BY VOLUME                     8.4      10.2      12.5      15.4      19.5  |   48.3      39.8      36.8      37.0      37.8
    LB. PER 1000 LB. OF FUEL        1.275     1.338     1.416     1.551     1.678  |  2.794     2.486     2.334     2.303     2.313
    WEIGHT FLOW, LB./HR.             .152      .185      .222      .273      .338  |   .787      .667      .610      .584      .575

NITROGEN DIOXIDE

    PPM BY VOLUME                     8.8      11.5      12.7      15.5      14.4  |    9.4      10.2      12.4      12.1      11.5
    LB. PER 1000 LB. OF FUEL        2.070     2.330     2.206     2.402     1.901  |   .836      .978     1.210     1.158     1.080
    WEIGHT FLOW, LB./HR.             .246      .322      .346      .423      .383  |   .235      .263      .316      .293      .268

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                    17.2      21.7      25.2      30.9      34.0  |   57.7      50.0      49.3      49.1      49.3
    LB. PER 1000 LB. OF FUEL        4.025     4.381     4.377     4.780     4.474  |  5.120     4.789     4.788     4.689     4.626
    WEIGHT FLOW, LB./HR.             .479      .605      .687      .841      .901  |  1.441     1.286     1.252     1.189     1.150

***** NOTES *****
      1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
      2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
      3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                          EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-180      S/N    P-595     DATE OF TEST    6/15/71    TYPE OF FUEL AVIA.KERO.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED SHP=  160.0       RATED EGT=1150.0 DEG.F     RATED SPEED= 40700.0
DEW PT.= 36.0     REL.HUMIDITY=  9.0 PERCENT     SPECIFIC HUMIDITY=  .00462     BAROMETRIC PRESSURE=28.64 IN HGA
                                               SHP LOADING ONLY                     COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                  1        6       11       16       20   |    22        19        15        10        5
PERCENT MAX. CORRECTED POWER        0.0     25.4     49.4     73.9     98.7   |   97.7      72.9      48.8      25.0      0.0
CORRECTED SHAFT HP                  0.0     40.7     79.0    118.2    157.8   |  156.4     116.6      78.0      40.0      0.0
MEASURED SHAFT HP                   0.0     40.7     79.1    118.3    157.9   |  157.2     117.2      78.3      40.1      0.0
EXHAUST GAS TEMP., DEG.F          510.0    580.0    660.0    740.0    850.0   | 1150.0    1150.0    1150.0    1150.0    1150.0
SHAFT SPEED, N1, RPM            41600.0  41400.0  41200.0  41100.0  40900.0   |40700.0   40700.0   40800.0   40800.0   40800.0
COMPRESSOR INLET TEMP.,DEG.F      105.0    106.0    107.0    107.0    107.0   |  112.0     112.0     110.0     110.0     110.0
COMPRESSOR DSCHG. PRES.,PSIA       53.4     52.9     52.6     52.4     51.9   |   49.6      49.7      48.5      47.2      45.7
CORRECTED BLEED FLOW, LB/MIN       0.00     0.00     0.00     0.00     0.00   |  63.40     86.16    104.91    116.77    133.42
CORRECTED FUEL FLOW , LB/HR       114.0    133.0    153.0    174.0    205.0   |  266.5     261.5     264.5     251.5     241.5
FA RATIO CALC. FROM EMISSION      .0068    .0077    .0091    .0103    .0120   |  .0176     .0163     .0160     .0161     .0164
EQUIVALENCE RATIO                  .099     .112     .133     .150     .175   |   .257      .239      .234      .235      .240
*****************************************SUMMARY OF REDUCED EMISSION DATA*************************************************
CARBON DIOXIDE
                                                                              |
    PERCENT BY VOLUME              1.38     1.55     1.83     2.08     2.42   |   3.55      3.30      3.23      3.25      3.32
    LB. CO2 PER LB. OF FUEL        3.10     3.10     3.10     3.11     3.11   |   3.14      3.13      3.13      3.12      3.12
    WEIGHT FLOW, LB./HR.          353.4    412.0    474.0    540.7    638.0   |  836.8     818.1     826.6     786.1     753.8

CARBON MONOXIDE
                                                                              |
    PPM BY VOLUME                 190.9    227.3    273.6    261.2    288.3   |  197.3     265.7     289.6     324.3     331.5
    LB. PER 1000 LB. OF FUEL     27.371   28.955   29.413   24.884   23.555   | 11.079    16.024    17.819    19.847    19.865
    WEIGHT FLOW, LB./HR.          3.120    3.851    4.500    4.330    4.829   |  2.953     4.190     4.713     4.992     4.797

UNBURNED HYDROCARBONS AS PPM CARBON
                                                                              |
    PPM BY VOLUME                  50.8     55.5     56.3     49.0     36.9   |    6.3       5.7       7.9      13.0      14.8
    LB. PER 1000 LB. OF FUEL      4.162    4.039    3.458    2.670    1.726   |   .201      .196      .277      .456      .507
    WEIGHT FLOW, LB./HR.           .474     .537     .529     .465     .354   |   .054      .051      .073      .115      .123

NITRIC OXIDE
                                                                              |
    PPM BY VOLUME                   8.7     11.2     13.1     17.3     23.3   |   51.6      43.1      37.8      35.4      35.6
    LB. PER 1000 LB. OF FUEL      1.333    1.535    1.512    1.764    2.041   |  3.102     2.786     2.493     2.320     2.285
    WEIGHT FLOW, LB./HR.           .152     .204     .231     .307     .418   |   .827      .729      .659      .584      .552

NITROGEN DIOXIDE
                                                                              |
    PPM BY VOLUME                   8.7     11.2     12.5     14.1     15.3   |    8.8      11.1      15.0      14.7      14.6
    LB. PER 1000 LB. OF FUEL      2.043    2.345    2.206    2.200    2.054   |   .815     1.099     1.516     1.475     1.440
    WEIGHT FLOW, LB./HR.           .233     .312     .338     .383     .421   |   .217      .287      .401      .371      .348

TOTAL OXIDES OF NITROGEN AS NO2  (3)
                                                                              |
    PPM BY VOLUME                  17.4     22.4     25.6     31.3     38.6   |   60.4      54.2      52.8      50.1      50.2
    LB. PER 1000 LB. OF FUEL      4.086    4.698    4.524    4.905    5.184   |  5.571     5.370     5.339     5.032     4.942
    WEIGHT FLOW, LB./HR.           .466     .625     .692     .854    1.063   |  1.485     1.404     1.412     1.265     1.194

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                  EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-180        S/N     P-593    DATE OF TEST    6/16/71    TYPE OF FUEL AVIA-KERO.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843    RATED SHP=  160.0    RATED EGT=1150.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 34.0     REL.HUMIDITY= 15.0 PERCENT     SPECIFIC HUMIDITY=  .00425    BAROMETRIC PRESSURE=28.62 IN HGA
                                                SHP LOADING ONLY                           COMBINATION SHP/BLEED LOADING
                                         1         6        11        16        20  |      22        19        15        10         5         3
POWER SETTING NUMBER
PERCENT MAX. CORRECTED POWER           0.0      25.1      49.8      74.7      99.8  |    99.1      74.0      49.0      24.6       0.0       0.0
CORRECTED SHAFT HP                     0.0      40.2      79.7     119.6     159.6  |   158.6     118.4      78.4      39.4       0.0       0.0
MEASURED SHAFT HP                      0.0      39.7      79.1     118.6     158.3  |   157.5     117.7      78.5      39.3       0.0       0.0
EXHAUST GAS TEMP., DEG.F             500.0     585.0     655.0     740.0     830.0  |  1150.0    1150.0    1150.0    1150.0    1150.0     950.0
SHAFT SPEED, N1, RPM               41600.0   41400.0   41200.0   41200.0   41000.0  | 40800.0   40900.0   40900.0   41000.0   41100.0   41300.0
COMPRESSOR INLET TEMP.,DEG.F          94.0      95.0      98.0      98.0      98.0  |   100.0     101.0     108.0     106.0     105.0     104.0
COMPRESSOR DSCHG. PRES.,PSIA          55.4      54.4      54.1      54.2      54.0  |    52.5      51.6      49.9      48.9      47.1      49.8
CORRECTED BLEED FLOW, LB/MIN          0.00      0.00      0.00      0.00      0.00  |   64.40     86.16    100.06    115.64    132.58     99.73
CORRECTED FUEL FLOW , LB/HR          118.0     139.0     156.0     180.0     208.0  |   276.5     268.5     256.5     248.5     241.5     206.5
FA RATIO CALC. FROM EMISSION         .0067     .0081     .0092     .0104     .0121  |   .0165     .0163     .0162     .0160     .0165     .0127
EQUIVALENCE RATIO                     .098      .118      .134      .152      .176  |    .241      .238      .236      .233      .242      .185
*****************************************************SUMMARY OF REDUCED EMISSION DATA*************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                 1.36      1.64      1.87      2.12      2.45  |    3.35      3.30      3.27      3.23      3.35      2.56
    LB. CO2 PER LB. OF FUEL           3.12      3.12      3.12      3.12      3.12  |    3.13      3.13      3.13      3.13      3.13      3.11
    WEIGHT FLOW, LB./HR.             367.6     433.4     486.6     561.7     649.3  |   866.8     841.3     802.8     777.4     755.5     643.1

CARBON MONOXIDE

    PPM BY VOLUME                    143.5     164.4     185.7     206.7     236.9  |   200.6     214.3     247.7     258.7     265.7     300.0
    LB. PER 1000 LB. OF FUEL        20.864    19.925    19.756    19.373    19.222  |  11.952    12.931    15.082    15.953    15.809    23.216
    WEIGHT FLOW, LB./HR.             2.462     2.770     3.082     3.487     3.998  |   3.305     3.472     3.869     3.964     3.818     4.796

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                     25.0      26.4      24.5      22.4      19.0  |     4.2       3.3       4.8       6.4       8.1      25.8
    LB. PER 1000 LB. OF FUEL         2.079     1.824     1.492     1.203      .883  |    .142      .115      .164      .226      .274     1.139
    WEIGHT FLOW, LB./HR.              .245      .254      .233      .216      .184  |    .039      .031      .043      .056      .066      .235

NITRIC OXIDE

    PPM BY VOLUME                     10.1      14.7      17.7      21.3      25.8  |    44.9      44.5      39.8      39.0      38.9      24.2
    LB. PER 1000 LB. OF FUEL         1.578     1.905     2.018     2.144     2.242  |   2.866     2.876     2.600     2.579     2.478     2.005
    WEIGHT FLOW, LB./HR.              .186      .265      .315      .386      .466  |    .792      .772      .667      .641      .598      .414

NITROGEN DIOXIDE

    PPM BY VOLUME                      7.4       9.4      11.0      12.2      13.0  |    10.1       9.7      12.1      11.8      11.9      14.0
    LB. PER 1000 LB. OF FUEL         1.758     1.956     1.924     1.879     1.731  |    .989      .958     1.206     1.198     1.164     1.781
    WEIGHT FLOW, LB./HR.              .207      .272      .300      .334      .360  |    .274      .257      .309      .298      .281      .368

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                     17.5      24.5      28.7      33.6      38.8  |    55.0      54.2      51.9      50.9      50.8      39.2
    LB. PER 1000 LB. OF FUEL         4.178     4.877     5.018     5.166     5.168  |   5.383     5.368     5.191     5.152     4.963     4.854
    WEIGHT FLOW, LB./HR.              .493      .674      .783      .930     1.075  |   1.488     1.441     1.332     1.280     1.194     1.002

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY

ENGINE GTCP85-98CK S/N P-35648 DATE OF TEST 6/7/71 TYPE OF FUEL AV.KEROS.

FUEL H/C=1.920 STOICHIOMETRIC F/A= .06843 RATED SHP= 160.0 RATED EGT=1150.0 DEG.F RATED SPEED= 43700.0
DEW PT.= 17.0 REL.HUMIDITY= 6.0 PERCENT SPECIFIC HUMIDITY= .00194 BAROMETRIC PRESSURE=28.65 IN HGA

	SHP LOADING ONLY					COMBINATION SHP/BLEED LOADING				
POWER SETTING NUMBER	1	6	11	16	20	22	19	15	10	5
PERCENT MAX. CORRECTED POWER	0.0	25.1	49.4	73.9	97.3	94.5	71.6	47.5	24.2	0.0
CORRECTED SHAFT HP	0.0	40.2	79.1	119.2	155.7	151.1	114.6	76.0	38.7	0.0
MEASURED SHAFT HP	0.0	39.7	78.3	117.3	155.4	154.3	116.5	77.3	39.1	0.0
EXHAUST GAS TEMP., DEG.F	560.0	630.0	700.0	805.0	930.0	1210.0	1150.0	1155.0	1160.0	1160.0
SHAFT SPEED, N1, RPM	41500.0	41400.0	41300.0	41100.0	41000.0	40700.0	40800.0	40800.0	40400.0	40900.0
COMPRESSOR INLET TEMP., DEG.F	90.0	93.0	95.0	98.0	104.0	130.0	125.0	126.0	120.0	114.0
COMPRESSOR DSCHG. PRES., PSIA	53.9	53.4	52.9	52.4	51.9	48.2	47.7	46.5	46.0	45.0
CORRECTED BLEED FLOW, LB/MIN	0.00	0.00	0.00	0.00	0.00	38.46	55.54	81.06	101.34	117.92
CORRECTED FUEL FLOW , LB/HR	122.0	141.6	161.8	184.0	214.0	258.0	244.0	244.0	242.0	234.0
FA RATIO CALC. FROM EMISSION	.0072	.0084	.0096	.0109	.0131	.0178	.0171	.0173	.0173	.0168
EQUIVALENCE RATIO	.105	.123	.141	.159	.191	.259	.250	.252	.253	.245

**********************SUMMARY OF REDUCED EMISSION DATA**********************

CARBON DIOXIDE										
PERCENT BY VOLUME	1.45	1.71	1.96	2.22	2.66	3.59	3.46	3.49	3.50	3.40
LB. CO2 PER LB. OF FUEL	3.11	3.12	3.12	3.13	3.13	3.14	3.13	3.13	3.13	3.13
WEIGHT FLOW, LB./HR.	379.0	441.3	505.2	575.1	669.1	809.0	764.3	764.3	758.1	732.4
CARBON MONOXIDE										
PPM BY VOLUME	160.7	164.9	158.7	179.8	212.9	196.2	212.3	216.9	216.0	235.1
LB. PER 1000 LB. OF FUEL	21.862	19.158	17.138	16.133	15.957	10.895	12.228	12.384	12.303	13.789
WEIGHT FLOW, LB./HR.	2.667	2.713	2.773	2.968	3.415	2.811	2.984	3.022	2.977	3.227
UNBURNED HYDROCARBONS AS PPM CARBON										
PPM BY VOLUME	61.1	41.5	29.2	22.0	19.6	15.7	26.3	24.2	24.2	25.6
LB. PER 1000 LB. OF FUEL	4.750	2.757	1.695	1.127	.938	.497	.866	.791	.789	.858
WEIGHT FLOW, LB./HR.	.580	.390	.274	.207	.179	.128	.211	.193	.191	.201
NITRIC OXIDE										
PPM BY VOLUME	1.2	9.5	12.8	17.4	22.4	35.3	31.6	30.2	30.5	29.3
LB. PER 1000 LB. OF FUEL	.168	1.180	1.392	1.669	1.796	2.101	1.947	1.850	1.864	1.841
WEIGHT FLOW, LB./HR.	.021	.167	.225	.307	.384	.542	.475	.451	.451	.431
NITROGEN DIOXIDE										
PPM BY VOLUME	6.5	7.7	7.8	8.0	8.2	6.7	7.6	8.5	8.1	9.0
LB. PER 1000 LB. OF FUEL	1.457	1.464	1.297	1.183	1.013	.608	.721	.800	.756	.870
WEIGHT FLOW, LB./HR.	.178	.207	.210	.218	.217	.157	.176	.195	.183	.204
TOTAL OXIDES OF NITROGEN AS NO2 (3)										
PPM BY VOLUME	7.7	17.2	20.6	25.4	30.6	42.0	39.2	38.8	38.6	38.3
LB. PER 1000 LB. OF FUEL	1.715	3.273	3.431	3.741	3.767	3.829	3.706	3.636	3.614	3.693
WEIGHT FLOW, LB./HR.	.209	.463	.555	.689	.806	.988	.904	.887	.875	.864

***** NOTES *****

1. ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
2. EQUIVALENCE RATIO CALCULATED FROM CO2, CO, AND HC DATA AND FUEL COMPOSITION.
3. TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).

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                                          EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-98D        S/N   P-27692    DATE OF TEST     5/3/71   TYPE OF FUEL        JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877    RATED SHP=  160.0    RATED EGT=1250.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 23.0     REL.HUMIDITY= 10.0 PERCENT     SPECIFIC HUMIDITY=  .00259    BAROMETRIC PRESSURE=28.72 IN HGA
                                                 SHP LOADING ONLY                          COMBINATION SHP/BLEED LOADING
 POWER SETTING NUMBER                   1          6          11         16         20   |    22        19        15        10          5
PERCENT MAX. CORRECTED POWER           0.0       25.9       51.7       77.6       90.8   |   50.9      37.7      25.2      25.1        0.0
CORRECTED SHAFT HP                     0.0       41.5       82.8      124.2      145.4   |   81.5      60.4      40.3      40.1        0.0
MEASURED SHAFT HP                      0.0       40.4       80.6      120.9      141.7   |   81.0      60.0      40.1      40.0        0.0
EXHAUST GAS TEMP., DEG.F             615.0      680.0      750.0      865.0      985.0   | 1250.0    1250.0    1250.0    1235.0     1200.0
SHAFT SPEED, N1, RPM               41200.0    41100.0    41000.0    41000.0    40900.0   |40700.0   40700.0   40800.0   40700.0    40800.0
COMPRESSOR INLET TEMP.,DEG.F          92.0       74.0       74.0       74.0       75.0   |   96.0      96.0      98.0     100.0      100.0
COMPRESSOR DSCHG. PRES.,PSIA          51.9       51.4       51.7       51.7       51.6   |   52.1      50.7      49.1      45.1       43.8
CORRECTED BLEED FLOW, LB/MIN          0.00       0.00       0.00       0.00       0.00   |  35.72     55.01     75.37
CORRECTED FUEL FLOW , LB/HR          125.5      152.0      172.4      197.8      232.0   |  277.5     258.0     267.0     206.0      201.0
FA RATIO CALC. FROM EMISSION         .0073      .0085      .0101      .0119      .0141   |  .0186     .0180     .0183     .0186      .0173
EQUIVALENCE RATIO                     .107       .124       .147       .173       .204   |   .270      .262      .267      .271       .251
*******************************************SUMMARY OF REDUCED EMISSION DATA**********************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                 1.49       1.73       2.06       2.41       2.86   |   3.78      3.67      3.74      3.79       3.51
    LB. CO2 PER LB. OF FUEL           3.11       3.12       3.12       3.13       3.14   |   3.15      3.15      3.15      3.15       3.15
    WEIGHT FLOW, LB./HR.             390.3      473.6      537.8      618.3      727.4   |  875.4     813.6     841.9     649.2      632.4

CARBON MONOXIDE

    PPM BY VOLUME                    212.9      229.4      262.3      275.0      260.8   |  130.7     142.5     146.0     171.4      214.6
    LB. PER 1000 LB. OF FUEL        28.258     26.258     25.307     22.693     18.215   |  6.934     7.797     7.845     9.078     12.231
    WEIGHT FLOW, LB./HR.             3.546      3.991      4.363      4.489      4.226   |  1.924     2.012     2.095     1.870      2.459

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                     53.6       49.6       43.5       33.7       16.3   |    1.3       2.1       1.7        .3        4.7
    LB. PER 1000 LB. OF FUEL         4.068      3.243      2.401      1.592       .649   |   .038      .066      .052      .009       .153
    WEIGHT FLOW, LB./HR.              .511       .493       .414       .315       .151   |   .011      .017      .014      .002       .031

NITRIC OXIDE

    PPM BY VOLUME                      8.1       10.1       14.4       21.9       32.4   |   60.9      58.9      56.5      55.2       48.3
    LB. PER 1000 LB. OF FUEL         1.150      1.244      1.488      1.940      2.421   |  3.459     3.454     3.250     3.132      2.950
    WEIGHT FLOW, LB./HR.              .144       .189       .257       .384       .562   |   .960      .891      .868      .645       .593

NITROGEN DIOXIDE

    PPM BY VOLUME                     13.3       13.8       14.8       14.0       12.8   |    8.6       9.0       9.7       9.1       11.5
    LB. PER 1000 LB. OF FUEL         2.901      2.587      2.350      1.896      1.472   |   .753      .805      .856      .795      1.076
    WEIGHT FLOW, LB./HR.              .364       .393       .405       .375       .342   |   .209      .208      .229      .164       .216

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                     21.4       23.9       29.2       35.9       45.2   |   69.5      67.9      66.2      64.3       59.8
    LB. PER 1000 LB. OF FUEL         4.663      4.494      4.631      4.871      5.184   |  6.056     6.101     5.839     5.598      5.599
    WEIGHT FLOW, LB./HR.              .585       .683       .798       .963      1.203   |  1.681     1.574     1.559     1.153      1.125

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                   EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-98D       S/N  P-27857      DATE OF TEST      5/6/71    TYPE OF FUEL      JP-5

FUEL H/C=1.877   STOICHIOMETRIC F/A=  .06877    RATED SHP=  160.0    RATED EGT=1200.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 43.0    REL.HUMIDITY= 40.0 PERCENT      SPECIFIC HUMIDITY=  .00609     BAROMETRIC PRESSURE=28.78 IN HGA
                                               SHP LOADING ONLY                           COMBINATION SHP/BLEED LOADING
                                                                               |
POWER SETTING NUMBER                     1        6        11        16        20 |   22       19       15       10        5
PERCENT MAX. CORRECTED POWER           0.0     25.1      49.8      74.5      99.6 |  98.2     73.9     49.2     24.9      0.0
CORRECTED SHAFT HP                     0.0     40.1      79.6     119.2     159.4 | 157.1    118.3     78.8     39.8      0.0
MEASURED SHAFT HP                      0.0     39.3      77.9     116.7     155.8 | 153.9    115.5     76.9     38.8      0.0
EXHAUST GAS TEMP., DEG.F             540.0    605.0     670.0     765.0     870.0 |1230.0   1195.0   1185.0   1175.0   1170.0
SHAFT SPEED, N1, RPM               41100.0  40950.0   40850.0   40700.0   40600.0 |40100.0 40300.0  40300.0  40400.0  40500.0
COMPRESSOR INLET TEMP.,DEG.F          79.0     78.0      77.0      77.0      76.0 |  78.0     75.0     74.0     73.0     81.0
COMPRESSOR DSCHG. PRES.,PSIA          57.9     56.6      56.9      56.5      56.4 |  53.4     52.7     51.7     50.5     49.0
CORRECTED BLEED FLOW, LB/MIN          0.00     0.00      0.00      0.00      0.00 | 64.79    79.86    95.59   109.17   119.55
CORRECTED FUEL FLOW , LB/HR          112.5    137.0     159.5     184.5     211.0 | 284.5    273.0    264.0    255.0    234.0
FA RATIO CALC. FROM EMISSION         .0096    .0079     .0094     .0102     .0127 | .0197    .0184    .0181    .0175    .0177
EQUIVALENCE RATIO                    .1402     .115      .137      .148      .185 |  .287     .267     .264     .255     .257
**********************************************SUMMARY OF REDUCED EMISSION DATA**********************************************
CARBON DIOXIDE
                                                                               |
   PERCENT BY VOLUME                 1.962     1.61      1.90      2.05      2.57 |  4.00     3.73     3.68     3.56     3.59
   LB. CO2 PER LB. OF FUEL            3.13     3.10      3.11      3.10      3.12 |  3.15     3.15     3.14     3.14     3.15
   WEIGHT FLOW, LB./HR.              351.7    424.9     495.3     572.2     658.4 | 896.6    858.7    829.3    800.1    736.3

CARBON MONOXIDE
                                                                               |
   PPM BY VOLUME                     182.2    246.9     289.7     355.2     334.3 | 138.1    201.0    212.3    240.5    202.8
   LB. PER 1000 LB. OF FUEL         18.537   30.326    30.120    34.159    25.786 | 6.917   10.796   11.543   13.511   11.302
   WEIGHT FLOW, LB./HR.              2.085    4.155     4.804     6.302     5.441 | 1.968    2.947    3.047    3.445    2.645

UNBURNED HYDROCARBONS AS PPM CARBON
                                                                               |
   PPM BY VOLUME                      63.6     84.8      79.4      71.4      41.1 |  41.4     40.6     73.3     76.2     13.8
   LB. PER 1000 LB. OF FUEL          3.701    5.957     4.718     3.922     1.810 | 1.184    1.246    2.279    2.445     .439
   WEIGHT FLOW, LB./HR.               .416     .816      .753      .724      .382 |  .337     .340     .602     .624     .103

NITRIC OXIDE
                                                                               |
   PPM BY VOLUME                       3.6      7.0      10.1      13.3      20.9 |  60.3     56.7     50.6     47.5     42.8
   LB. PER 1000 LB. OF FUEL           .396     .917     1.120     1.374     1.728 | 3.234    3.265    2.948    2.857    2.554
   WEIGHT FLOW, LB./HR.               .045     .126      .179      .253      .365 |  .920     .891     .778     .729     .598

NITROGEN DIOXIDE
                                                                               |
   PPM BY VOLUME                      11.8     13.5      14.5      17.0      16.5 |   9.0      9.6     11.9     11.7     12.8
   LB. PER 1000 LB. OF FUEL          1.975    2.731     2.484     2.680     2.086 |  .744     .847    1.065    1.077    1.170
   WEIGHT FLOW, LB./HR.               .222     .374      .396      .495      .440 |  .212     .231     .281     .275     .274

TOTAL OXIDES OF NITROGEN AS NO2  (3)
                                                                               |
   PPM BY VOLUME                      15.5     20.5      24.6      30.3      37.4 |  69.3     66.3     62.5     59.2     55.6
   LB. PER 1000 LB. OF FUEL          2.583    4.137     4.201     4.786     4.736 | 5.702    5.853    5.585    5.458    5.085
   WEIGHT FLOW, LB./HR.               .291     .567      .670      .883      .999 | 1.622    1.598    1.474    1.392    1.190

***** NOTES *****
   1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
   2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
   3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                          EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-98         S/N   P-15454     DATE OF TEST      5/1/71    TYPE OF FUEL        JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877     RATED SHP=  160.0     RATED EGT=1250.0 DEG.F     RATED SPEED= 40700.0
DEW PT.= 17.0     REL.HUMIDITY= 18.0 PERCENT      SPECIFIC HUMIDITY=  .00194     BAROMETRIC PRESSURE=28.65 IN HGA
                                                     SHP LOADING ONLY                          COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                      1         6         11        16        20   |     22        19        15        10         5
PERCENT MAX. CORRECTED POWER            0.0      24.4       48.5      72.5      95.8   |    94.9      71.4      47.6      23.9       0.0
CORRECTED SHAFT HP                      0.0      39.0       77.6     116.0     153.3   |   151.9     114.2      76.2      38.2       0.0
MEASURED SHAFT HP                       0.0      38.3       76.4     114.3     151.6   |   150.5     113.2      75.5      37.8       0.0
EXHAUST GAS TEMP., DEG.F              550.0     600.0      690.0     800.0     950.0   |  1200.0    1200.0    1200.0    1200.0    1200.0
SHAFT SPEED, N1, RPM                41000.0   40900.0    40800.0   40700.0   40500.0   | 40200.0   40300.0   40300.0   40400.0   40400.0
COMPRESSOR INLET TEMP.,DEG.F           85.0      85.0       88.0      90.0      94.0   |    96.0      96.0      95.0      94.0      92.0
COMPRESSOR DSCHG. PRES.,PSIA           54.2      53.9       53.6      53.1      52.5   |    51.6      50.4      49.4      47.7      46.4
CORRECTED BLEED FLOW, LB/MIN           0.00      0.00       0.00      0.00      0.00   |   49.69     71.53     89.87    106.65    122.05
CORRECTED FUEL FLOW , LB/HR           113.0     132.0      154.0     177.0     208.8   |   261.5     251.5     246.5     241.5     231.7
FA RATIO CALC. FROM EMISSION          .0067     .0081      .0096     .0113     .0138   |   .0183     .0182     .0179     .0179     .0176
EQUIVALENCE RATIO                      .098      .117       .140      .164      .201   |    .267      .265      .260      .260      .255
*****************************************SUMMARY OF REDUCED EMISSION DATA*************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                  1.36      1.63       1.95      2.29      2.81   |    3.74      3.71      3.64      3.63      3.57
    LB. CO2 PER LB. OF FUEL            3.08      3.10       3.11      3.12      3.14   |    3.15      3.15      3.15      3.15      3.15
    WEIGHT FLOW, LB./HR.              347.7     408.5      478.9     552.8     655.1   |   824.8     793.0     770.6     760.4     729.0

CARBON MONOXIDE

    PPM BY VOLUME                     279.2     291.9      298.0     282.5     243.5   |   134.0     144.4     170.4     191.8     214.1
    LB. PER 1000 LB. OF FUEL         40.346    35.236     30.283    24.540    17.297   |   7.200     7.818     9.376    10.579    12.013
    WEIGHT FLOW, LB./HR.              4.559     4.651      4.664     4.344     3.612   |   1.883     1.966     2.311     2.555     2.783

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                     112.1      81.0       51.2      30.1      10.8   |     2.2       3.3       3.6       3.0]      4.3
    LB. PER 1000 LB. OF FUEL          9.260     5.586      2.972     1.494      .440   |    .067      .101      .114      .093] ?   .139
    WEIGHT FLOW, LB./HR.              1.046      .737       .458      .264      .092   |    .018      .025      .028      .023]     .032

NITRIC OXIDE

    PPM BY VOLUME                       2.5       4.9        8.5      13.6      22.5   |    39.2      39.3      37.6      36.4      34.7
    LB. PER 1000 LB. OF FUEL           .388      .629       .923     1.270     1.714   |   2.258     2.279     2.218     2.152     2.084
    WEIGHT FLOW, LB./HR.               .044      .083       .142      .225      .358   |    .591      .573      .547      .520      .483

NITROGEN DIOXIDE

    PPM BY VOLUME                       9.4      10.4       11.1      10.6       9.0   |     4.9       5.1       5.9       5.9       7.1
    LB. PER 1000 LB. OF FUEL          2.238     2.059      1.850     1.517     1.054   |    .429      .455      .531      .536      .652
    WEIGHT FLOW, LB./HR.               .253      .272       .285      .269      .220   |    .112      .114      .131      .129      .151

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                      11.9      15.2       19.6      24.3      31.6   |    44.1      44.4      43.5      42.3      41.7
    LB. PER 1000 LB. OF FUEL          2.834     3.024      3.266     3.464     3.682   |   3.891     3.948     3.932     3.835     3.847
    WEIGHT FLOW, LB./HR.               .320      .399       .503      .613      .769   |   1.018      .993      .969      .926      .891

***** NOTES *****
   1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
   2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
   3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                             EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-98        S/N   P-15257     DATE OF TEST    5/18/71     TYPE OF FUEL AV.KEROS.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843     RATED SHP=  160.0      RATED EGT=1200.0 DEG.F     RATED SPEED= 40700.0
DEW PT.= 10.0     REL.HUMIDITY=  8.0 PERCENT      SPECIFIC HUMIDITY=  .00135    BAROMETRIC PRESSURE=28.84 IN HGA
                                                 SHP LOADING ONLY                          COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                  1        6        11        16        20   |     22        19        15        10         5
PERCENT MAX. CORRECTED POWER        0.0     24.2      48.3      72.3      95.8   |   95.7      71.7      47.7      23.9       0.0
CORRECTED SHAFT HP                  0.0     38.4      77.3     115.7     153.2   |  153.1     114.8      76.4      38.3       0.0
MEASURED SHAFT HP                   0.0     38.3      76.4     114.3     152.0   |  151.3     113.5      75.6      37.9       0.0
EXHAUST GAS TEMP., DEG.F          530.0    610.0     695.0     785.0     910.0   | 1200.0    1200.0    1200.0    1200.0    1200.0
SHAFT SPEED, N1, RPM            41000.0  40900.0   40800.0   40700.0   40600.0   |40400.0   40400.0   40400.0   40500.0   40560.0
COMPRESSOR INLET TEMP.,DEG.F       84.0     84.0      85.0      85.0      90.0   |   85.0      86.0      88.0      88.0      88.0
COMPRESSOR DSCHG. PRES.,PSIA       54.9     55.2      54.9      54.6      54.0   |   53.5      52.0      53.2      50.6      48.2
CORRECTED BLEED FLOW, LB/MIN       0.00     0.00      0.00      0.00      0.00   |  45.64     70.85     45.99     83.42    116.49
CORRECTED FUEL FLOW , LB/HR       116.8    136.5     158.6     182.0     219.5   |  270.0     270.0     274.0     262.0     242.0
FA RATIO CALC. FROM EMISSION      .0073    .0085     .0100     .0117     .0137   |  .0184     .0190     .0186     .0191     .0189
EQUIVALENCE RATIO                  .107     .124      .146      .171      .200   |   .270      .277      .273      .279      .276
*************************************************SUMMARY OF REDUCED EMISSION DATA***************************************************
CARBON DIOXIDE
                                                                                 |
     PERCENT BY VOLUME             1.47     1.71      2.02      2.37      2.78   |   3.74      3.85      3.78      3.87      3.83
     LB. CO2 PER LB. OF FUEL       3.06     3.09      3.11      3.12      3.13   |   3.14      3.14      3.14      3.14      3.14
     WEIGHT FLOW, LB./HR.         357.5    421.7     493.5     567.6     686.8   |  848.8     848.9     861.6     823.9     760.5

CARBON MONOXIDE                                                                  |
                                                                                 |
     PPM BY VOLUME                288.6    269.1     263.5     253.8     219.1   |  120.8     122.7     115.5     117.0     137.7 ]
     LB. PER 1000 LB. OF FUEL    38.285   31.026    25.788    21.258    15.710   |  6.460     6.377     6.111     6.056     7.195 ] ?
     WEIGHT FLOW, LB./HR.         4.472    4.235     4.095     3.869     3.448   |  1.744     1.722     1.674     1.587     1.741 ]

UNBURNED HYDROCARBONS AS PPM CARBON                                              |
                                                                                 |
     PPM BY VOLUME                158.9     89.3      37.3      16.8       3.3   |    2.7        .7       1.1        .6        .8
     LB. PER 1000 LB. OF FUEL    12.050    5.885     2.086      .806      .135   |   .081      .022      .032      .019      .024
     WEIGHT FLOW, LB./HR.         1.407     .803      .331      .147      .030   |   .022      .006      .009      .005      .006

NITRIC OXIDE                                                                     |
                                                                                 |
     PPM BY VOLUME                  7.1      9.3      18.7      26.8      36.7   |   59.9      58.0      60.1      60.6      54.2
     LB. PER 1000 LB. OF FUEL     1.011    1.151     1.960     2.401     2.818   |  3.431     3.231     3.409     3.364     3.037
     WEIGHT FLOW, LB./HR.          .118     .157      .311      .437      .619   |   .926      .872      .934      .881      .735

NITROGEN DIOXIDE                                                                 |
                                                                                 |
     PPM BY VOLUME                 12.8     17.0      14.1      13.5      12.2   |    5.4       5.4       6.3       4.0       5.0
     LB. PER 1000 LB. OF FUEL     2.785    3.227     2.264     1.855     1.440   |   .473      .460      .544      .341      .430
     WEIGHT FLOW, LB./HR.          .325     .440      .360      .338      .316   |   .128      .124      .149      .089      .104

TOTAL OXIDES OF NITROGEN AS NO2  (3)                                             |
                                                                                 |
     PPM BY VOLUME                 19.9     26.4      32.8      40.2      48.9   |   65.3      63.4      66.4      64.6      59.3
     LB. PER 1000 LB. OF FUEL     4.335    4.992     5.269     5.536     5.761   |  5.733     5.413     5.771     5.498     5.086
     WEIGHT FLOW, LB./HR.          .506     .681      .837     1.008     1.265   |  1.548     1.462     1.581     1.440     1.231

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                              EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-98       S/N   P-15541     DATE OF TEST    5/21/71    TYPE OF FUEL AV.KEROS.

FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843     RATED SHP=  160.0     RATED EGT=1250.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 28.0     REL.HUMIDITY= 13.0 PERCENT      SPECIFIC HUMIDITY=  .00328    BAROMETRIC PRESSURE=28.58 IN HGA
                                              SHP LOADING ONLY                              COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                    1         6        11        16        20   |     22        19        15        10         5
PERCENT MAX. CORRECTED POWER          0.0      24.2      48.1      71.7      95.5   |   94.7      70.7      47.1      23.6       0.0
CORRECTED SHAFT HP                    0.0      38.7      77.0     114.8     152.8   |  151.5     113.1      75.4      37.8       0.0
MEASURED SHAFT HP                     0.0      38.1      76.0     113.5     150.9   |  149.8     112.1      74.7      37.4       0.0
EXHAUST GAS TEMP., DEG.F            550.0     635.0     740.0     865.0     995.0   | 1250.0    1250.0    1250.0    1250.0    1250.0
SHAFT SPEED, N1, RPM              41000.0   40700.0   40600.0   40400.0   40300.0   |40000.0   39900.0   39900.0   40000.0   40000.0
COMPRESSOR INLET TEMP.,DEG.F         88.0      92.0      95.0      96.0      95.0   |   96.0      98.0      98.0      97.0      96.0
COMPRESSOR DSCHG. PRES.,PSIA         51.9      51.4      51.3      51.2      51.0   |   49.0      48.0      46.9      45.7      44.0
CORRECTED BLEED FLOW, LB/MIN         0.00      0.00      0.00      0.00      0.00   |  40.24     65.93     83.77    101.01    116.07
CORRECTED FUEL FLOW , LB/HP         117.0     125.0     158.0     182.0     213.4   |  258.3     253.4     248.4     243.4     233.4
FA RATIO CALC. FROM EMISSION        .0070     .0084     .0099     .0120     .0145   |  .0195     .0195     .0195     .0192     .0191
EQUIVALENCE RATIO                    .102      .123      .145      .175      .212   |   .286      .285      .285      .281      .279
*****************************************SUMMARY OF REDUCED EMISSION DATA*************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                1.38      1.68      1.99      2.42      2.93   |   3.96      3.95      3.94      3.89      3.86
    LB. CO2 PER LB. OF FUEL          3.04      3.06      3.08      3.11      3.13   |   3.14      3.14      3.14      3.14      3.14
    WEIGHT FLOW, LB./HR.            356.0     383.1     487.3     565.4     667.4   |  811.9     795.8     780.2     763.9     732.7

CARBON MONOXIDE

    PPM BY VOLUME                   282.1     319.9     328.0     296.4     196.1   |   90.1     100.9     109.2     114.5     127.6
    LB. PER 1000 LB. OF FUEL       39.535    37.133    32.414    24.188    13.304   |  4.552     5.100     5.535     5.875     6.609
    WEIGHT FLOW. LB./HR.            4.626     4.642     5.121     4.402     2.839   |  1.176     1.292     1.375     1.430     1.542

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                   222.1     169.8     121.9      73.6      54.1   |   45.2      68.3      57.6      80.1      56.6
    LB. PER 1000 LB. OF FUEL       17.788    11.266     6.883     3.433     2.100   |  1.307     1.975     1.670     2.349     1.674
    WEIGHT FLOW, LB./HR.            2.081     1.409     1.088      .625      .448   |   .338      .500      .415      .572      .391

NITRIC OXIDE

    PPM BY VOLUME                     5.2       9.2      14.7      23.9      40.4   |   61.1      61.3      59.8      59.6      56.3
    LB. PER 1000 LB. OF FUEL         .785     1.144     1.560     2.092     2.935   |  3.310     3.323     3.247     3.275     3.124
    WEIGHT FLOW, LB./HR.             .092      .143      .246      .381      .626   |   .855      .842      .807      .797      .729

NITROGEN DIOXIDE

    PPM BY VOLUME                    13.1      15.0      15.3      13.8       7.7   |    4.9       5.1       4.6       4.1       4.6
    LB. PER 1000 LB. OF FUEL        3.009     2.866     2.481     1.846      .857   |   .405      .422      .385      .347      .389
    WEIGHT FLOW, LB./HR.             .352      .358      .392      .336      .183   |   .105      .107      .096      .085      .091

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                    18.3      24.2      30.0      37.7      48.1   |   66.0      66.4      64.4      63.7      60.9
    LB. PER 1000 LB. OF FUEL        4.212     4.620     4.872     5.053     5.357   |  5.479     5.517     5.364     5.369     5.178
    WEIGHT FLOW, LB./HR.             .493      .577      .770      .920     1.143   |  1.415     1.398     1.332     1.307     1.209

***** NOTES *****
   1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
   2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
   3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY

ENGINE GTCP85-115 S/N P-18725 DATE OF TEST 5/13/71 TYPE OF FUEL JP5

RATED SHP= 160.0 RATED EGT=1250.0 DEG.F RATED SPEED= 40700.0

FUEL H/C=1.877 STOICHIOMETRIC F/A= .06877 SPECIFIC HUMIDITY= .00586 BAROMETRIC PRESSURE=28.78 IN HGA

DEW PT.= 42.0 REL.HUMIDITY= 25.0 PERCENT

	SHP LOADING ONLY					COMBINATION SHP/BLEED LOADING				
POWER SETTING NUMBER	1	6	11	16	20	22	19	15	10	5
PERCENT MAX. CORRECTED POWER	0.0	24.2	47.8	70.8	95.0	94.2	70.7	46.7	23.5	0.0
CORRECTED SHAFT HP	0.0	38.7	76.6	113.3	151.9	150.8	113.1	74.8	37.5	0.0
MEASURED SHAFT HP	0.0	38.2	76.0	113.7	151.3	150.9	113.2	75.6	37.8	0.0
EXHAUST GAS TEMP., DEG.F	520.0	615.0	740.0	900.0	1010.0	1200.0	1200.0	1195.0	1200.0	-0.0
SHAFT SPEED, N1, RPM	41100.0	40800.0	40600.0	40500.0	40400.0	40300.0	40300.0	40400.0	40400.0	-0.0
COMPRESSOR INLET TEMP.,DEG.F	82.0	85.0	93.0	105.0	96.0	102.0	102.0	114.0	109.0	-0.0
COMPRESSOR DSCHG. PRES.,PSIA	64.1	62.9	61.0	58.1	61.9	56.9	54.2	52.6	50.6	
CORRECTED BLEED FLOW, LB/MIN	0.00	0.00	0.00	0.00	0.00	33.08	49.86	65.58	85.03	0.00
CORRECTED FUEL FLOW , LB/HR	110.6	121.7	155.9	185.3	215.8	254.5	246.4	234.2	233.2	-0.0
FA RATIO CALC. FROM EMISSION	.0064	.0077	.0097	.0124	.0140	.0176	.0174	.0169	.0174	.0172
EQUIVALENCE RATIO	.093	.112	.141	.180	.204	.256	.253	.245	.254	.250

********************SUMMARY OF REDUCED EMISSION DATA********************

CARBON DIOXIDE										
PERCENT BY VOLUME	1.30	1.56	1.98	2.52	2.86	3.58	3.54	3.43	3.54	3.48
LB. CO2 PER LB. OF FUEL	3.11	3.11	3.13	3.14	3.14	3.15	3.15	3.14	3.14	3.14
WEIGHT FLOW, LB./HR.	343.4	378.7	437.7	581.2	677.8	802.0	775.6	736.4	733.1	0.0
CARBON MONOXIDE										
PPM BY VOLUME	196.1	215.9	211.4	221.1	217.2	161.8	200.4	226.7	243.1	264.3
LB. PER 1000 LB. OF FUEL	29.790	27.411	21.224	17.501	15.208	9.056	11.347	13.241	13.733	15.166
WEIGHT FLOW, LB./HR.	3.295	3.336	3.309	3.243	3.282	2.305	2.796	3.101	3.202	0.000
UNBURNED HYDROCARBONS AS PPM CARBON										
PPM BY VOLUME	58.2	54.7	27.0	13.3	6.9	3.0	3.3	4.4	5.0	8.0
LB. PER 1000 LB. OF FUEL	5.050	3.967	1.547	.602	.275	.097	.108	.148	.161	.263
WEIGHT FLOW, LB./HR.	.559	.483	.241	.111	.059	.025	.027	.035	.038	0.000
NITRIC OXIDE										
PPM BY VOLUME	5.4	8.7	19.5	32.0	39.8	48.5	49.9	46.6	48.4	45.1
LB. PER 1000 LB. OF FUEL	.871	1.181	2.102	2.710	2.985	2.907	3.029	2.916	2.928	2.772
WEIGHT FLOW, LB./HR.	.096	.144	.328	.502	.644	.740	.746	.683	.683	0.000
NITROGEN DIOXIDE										
PPM BY VOLUME	10.8	11.9	9.5	8.7	4.7	5.7	5.6	5.8	6.7	7.5
LB. PER 1000 LB. OF FUEL	2.684	2.474	1.574	1.136	.546	.520	.517	.557	.623	.709
WEIGHT FLOW, LB./HR.	.297	.301	.245	.210	.118	.132	.127	.130	.145	0.000
TOTAL OXIDES OF NITROGEN AS NO2 (3)										
PPM BY VOLUME	16.1	20.5	29.1	40.7	44.5	54.1	55.5	52.4	55.1	52.6
LB. PER 1000 LB. OF FUEL	4.019	4.284	4.796	5.291	5.122	4.977	5.161	5.028	5.112	4.959
WEIGHT FLOW, LB./HR.	.444	.521	.748	.980	1.105	1.267	1.272	1.178	1.192	0.000

***** NOTES *****

1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.

2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.

3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).

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                                 EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
                                 ********************************************
                                                6/8/71   TYPE OF FUEL AV.KEROS.
ENGINE   GTCP85-115        S/N   P-18781   DATE OF TEST                                  RATED SPEED= 40700.0
                                               RATED SHP=  160.0    RATED EGT=1250.0 DEG.F   
FUEL H/C=1.928    STOICHIOMETRIC F/A=  .06843  SPECIFIC HUMIDITY=  .00461   BAROMETRIC PRESSURE=28.72 IN HGA
DEW PT.= 36.0     REL.HUMIDITY= 15.0 PERCENT                                 COMBINATION SHP/BLEED LOADING
                                           SHP LOADING ONLY
POWER SETTING NUMBER                 1          6         11         16         20   |     22         19         15         10          5
PERCENT MAX. CORRECTED POWER       0.0       24.4       48.7       72.6       96.3   |   95.5       71.0       47.4       23.8        0.0
CORRECTED SHAFT HP                 0.0       39.0       78.0      116.1      154.1   |  152.8      113.6       75.9       38.0        0.0
MEASURED SHAFT HP                  0.0       38.6       77.1      115.1      153.1   |  152.4      114.3       76.2       38.2        0.0
EXHAUST GAS TEMP., DEG.F         545.0      620.0      710.0      820.0      960.0   | 1250.0     1250.0     1250.0     1250.0     1250.0
SHAFT SPEED, N1, RPM           41200.0    41200.0    41200.0    41000.0    40900.0   |40700.0    40700.0    40700.0    40800.0    40800.0
COMPRESSOR INLET TEMP.,DEG.F      92.0       91.0       91.0       94.0       96.0   |  100.0      110.0      108.0      108.0      108.0
COMPRESSOR DSCHG. PRES.,PSIA      53.5       54.4       54.4       54.1       53.9   |   51.9       50.2       48.7       47.0       45.3
CORRECTED BLEED FLOW, LB/MIN      0.00       0.00       0.00       0.00       0.00   |  44.80      58.98      79.58      96.03     111.77
CORRECTED FUEL FLOW , LB/HR      121.6      139.0      161.0      186.2      216.5   |  281.5      266.5      256.5      251.5      241.5
FA RATIO CALC. FROM EMISSION     .0066      .0083      .0100      .0118      .0136   |  .0183      .0180      .0179      .0178      .0177
EQUIVALENCE RATIO                 .096       .122       .147       .172       .199   |   .268       .263       .262       .261       .259
*****************************************SUMMARY OF REDUCED EMISSION DATA************************************************************
CARBON DIOXIDE
    PERCENT BY VOLUME             1.33       1.69       2.03       2.38       2.76   |   3.72       3.65       3.63       3.61       3.58
    LB. CO2 PER LB. OF FUEL       3.09       3.10       3.11       3.11       3.12   |   3.14       3.14       3.14       3.13       3.13
    WEIGHT FLOW, LB./HR.         376.3      431.1      504.2      579.6      676.0   |  884.3      834.5      804.7      788.2      755.7

CARBON MONOXIDE
    PPM BY VOLUME                194.6      221.2      254.7      275.2      259.5   |  144.8      164.6      181.5      213.7      261.0
    LB. PER 1000 LB. OF FUEL    28.705     25.944     24.797     22.928     19.663   |  7.782      9.018      9.978     11.808     14.509
    WEIGHT FLOW, LB./HR.         3.490      3.606      3.992      4.269      4.040   |  2.191      2.403      2.559      2.970      3.504

UNBURNED HYDROCARBONS AS PPM CARBON
    PPM BY VOLUME                 62.0       64.5       53.8       38.5       22.7   |    5.3       12.8       14.3       19.0       23.2
    LB. PER 1000 LB. OF FUEL     5.226      4.326      2.994      1.836       .932   |   .163       .402       .449       .599       .738
    WEIGHT FLOW, LB./HR.          .635       .601       .482       .342       .202   |   .046       .107       .115       .151       .178

NITRIC OXIDE
    PPM BY VOLUME                  3.7        5.8       10.6       14.7       22.8   |   37.5       37.0       35.3       34.9       32.0
    LB. PER 1000 LB. OF FUEL      .591       .728      1.104      1.309      1.759   |  2.159      2.174      2.078      2.064      1.909
    WEIGHT FLOW, LB./HR.          .071       .101       .178       .244       .381   |   .608       .579       .533       .519       .461

NITROGEN DIOXIDE
    PPM BY VOLUME                  7.5        8.9       11.4       10.8        9.5   |    4.9        5.2        6.7        6.7        8.1
    LB. PER 1000 LB. OF FUEL     1.807      1.718      1.821      1.476      1.119   |   .432       .472       .601       .608       .736
    WEIGHT FLOW, LB./HR.          .220       .239       .293       .275       .242   |   .121       .126       .154       .153       .178

TOTAL OXIDES OF NITROGEN AS NO2  (3)
    PPM BY VOLUME                 11.1       14.7       22.0       25.4       32.3   |   42.4       42.3       41.9       41.6       40.1
    LB. PER 1000 LB. OF FUEL     2.098      2.834      3.513      3.483      3.815   |  3.742      3.805      3.786      3.773      3.663
    WEIGHT FLOW, LB./HR.          .328       .394       .566       .648       .826   |  1.053      1.014       .971       .949       .885

***** NOTES *****
   1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
   2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
   3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-115        S/N   P-18702    DATE OF TEST    6/11/71   TYPE OF FUEL        JP4

FUEL H/C=1.990    STOICHIOMETRIC F/A=  .06806    RATED SHP=  160.0    RATED EGT=1250.0 DEG.F    RATED SPEED= 40800.0
DEW PT.= 35.0     REL.HUMIDITY= 17.0 PERCENT     SPECIFIC HUMIDITY=  .00454     BAROMETRIC PRESSURE=28.00 IN HGA
                                                    SHP LOADING ONLY                          COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                    1          6         11         16         20 |      22         19         15         10          5
PERCENT MAX. CORRECTED POWER          0.0       25.0       49.7       74.2       98.4 |    97.1       72.7       48.5       24.3        0.0
CORRECTED SHAFT HP                    0.0       40.0       79.6      118.7      157.5 |   155.4      116.3       77.6       38.8        0.0
MEASURED SHAFT HP                     0.0       38.6       76.9      115.1      153.5 |   152.4      114.3       76.4       38.1        0.0
EXHAUST GAS TEMP., DEG.F            540.0      620.0      705.0      830.0      955.0 |  1250.0     1250.0     1250.0     1250.0     1248.0
SHAFT SPEED, N1, RPM              41200.0    41200.0    41100.0    41000.0    41000.0 | 40700.0    40700.0    40800.0    40700.0    40800.0
COMPRESSOR INLET TEMP.,DEG.F         87.0       90.0       94.0       98.0      103.0 |   110.0      112.0      114.0      110.0      114.0
COMPRESSOR DSCHG. PRES.,PSIA         53.5       53.3       53.0       52.6       52.3 |    50.1       48.6       46.9       45.1       43.7
CORRECTED BLEED FLOW, LB/MIN         0.00       0.00       0.00       0.00       0.00 |   41.97      66.07      83.80      99.35     117.04
CORRECTED FUEL FLOW , LB/HR         116.4      138.0      158.0      183.2      212.0 |   266.5      262.5      246.5      241.5      232.5
FA RATIO CALC. FROM EMISSION        .0068      .0079      .0096      .0117      .0133 |   .0188      .0187      .0186      .0182      .0188
EQUIVALENCE RATIO                    .100       .117       .141       .172       .196 |    .276       .274       .274       .268       .276
*************************************************SUMMARY OF REDUCED EMISSION DATA*****************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME                1.37       1.60       1.93       2.35       2.69 |    3.78       3.76       3.74       3.66       3.77
    LB. CO2 PER LB. OF FUEL          3.08       3.08       3.09       3.10       3.11 |    3.12       3.12       3.12       3.12       3.12
    WEIGHT FLOW, LB./HR.            358.9      425.6      487.9      567.2      658.9 |   832.4      819.5      768.7      753.0      725.1

CARBON MONOXIDE

    PPM BY VOLUME                   195.0      235.4      279.1      301.6      259.3 |   192.2      206.6      245.5      243.4      245.6
    LB. PER 1000 LB. OF FUEL       27.856     28.915     28.408     25.264     19.099 |  10.102     10.922     13.013     13.188     12.924
    WEIGHT FLOW, LB./HR.            3.242      3.990      4.488      4.628      4.049 |   2.692      2.867      3.208      3.185      3.005

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                    55.8       54.9       48.1       31.2       18.3 |     9.9       11.8       13.4       13.9       12.5
    LB. PER 1000 LB. OF FUEL        4.553      3.855      2.796      1.493       .770 |    .296       .357       .407       .430       .376
    WEIGHT FLOW, LB./HR.             .530       .532       .442       .274       .163 |    .079       .094       .100       .104       .087

NITRIC OXIDE

    PPM BY VOLUME                     7.7       10.8       18.2       27.0       35.3 |    58.3       56.8       58.1       54.4       54.1
    LB. PER 1000 LB. OF FUEL        1.177      1.421      1.987      2.420      2.786 |   3.280      3.216      3.300      3.159      3.052
    WEIGHT FLOW, LB./HR.             .137       .196       .314       .443       .591 |    .874       .844       .813       .763       .709

NITROGEN DIOXIDE

    PPM BY VOLUME                     7.8        9.8        8.0        6.8        6.6 |     5.6        5.8        4.7        7.1        6.2
    LB. PER 1000 LB. OF FUEL        1.835      1.986      1.341       .939       .803 |    .485       .500       .409       .631       .537
    WEIGHT FLOW, LB./HR.             .214       .274       .212       .172       .170 |    .129       .131       .101       .152       .125

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                    15.5       20.6       26.2       33.8       41.9 |    63.9       62.5       62.8       61.5       60.3
    LB. PER 1000 LB. OF FUEL        3.638      4.164      4.387      4.648      5.075 |   5.513      5.431      5.469      5.474      5.216
    WEIGHT FLOW, LB./HR.             .424       .575       .693       .852      1.076 |   1.469      1.426      1.348      1.322      1.213

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                    EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP85-129        S/N   P-34763    DATE OF TEST    4/28/71   TYPE OF FUEL        JP4

FUEL H/C=1.990    STOICHIOMETRIC F/A=  .06806    RATED SHP= 160.0     RATED EGT=1150.0 DEG.F    RATED SPEED= 40700.0
DEW PT.= 30.0     REL.HUMIDITY= 23.0 PERCENT     SPECIFIC HUMIDITY=  .00357    BAROMETRIC PRESSURE=28.68 IN HGA
                                                 SHP LOADING ONLY                           COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                   1         6         11         16         20         22         19         15         9          4
PERCENT MAX. CORRECTED POWER         0.0      26.0       50.0       74.3       98.5       96.2       73.4       23.7       24.9        0.0
CORRECTED SHAFT HP                   0.0      41.6       80.0      118.8      157.5      155.7      117.3       79.7       39.8        0.0
MEASURED SHAFT HP                    0.0      40.8       78.5      116.9      155.2      153.4      115.5       78.5       39.2        0.0
EXHAUST GAS TEMP., DEG.F           530.0     590.0      655.0      735.0      850.0     1250.0     1240.0     1175.0     1130.0     1100.0
SHAFT SPEED, N1, RPH             41400.0   41500.0    41400.0    41300.0    41200.0    40700.0    40800.0    40900.0    40900.0    40900.0
COMPRESSOR INLET TEMP.,DEG.F        82.0      84.0       84.0       87.0       89.0       88.0       88.0       88.0       88.0       86.0
COMPRESSOR DSCHG. PRES.,PSIA
CORRECTED BLEED FLOW, LB/MIN        0.00      0.00       0.00       0.00       0.00      58.12      79.68      88.84      98.34     108.91
CORRECTED FUEL FLOW , LB/HR        111.0     129.0      148.0      169.0      203.5      283.2      276.2      259.4      239.5      226.5
FA RATIO CALC. FROM EMISSION       .0061     .0075      .0087      .0089      .0118      .0186      .0185      .0174      .0164      .0161
EQUIVALENCE RATIO                   .089      .111       .128       .130       .174       .273       .272       .255       .241       .236
***************************************************SUMMARY OF REDUCED EMISSION DATA**********************************************************
CARBON DIOXIDE

     PERCENT BY VOLUME              1.22      1.52       1.77       1.80       2.39       3.75       3.74       3.50       3.31       3.24
     LB. CO2 PER LB. OF FUEL        3.09      3.10       3.10       3.10       3.11       3.13       3.13       3.13       3.12       3.12
     WEIGHT FLOW, LB./HR.          343.1     399.6      459.3      524.3      633.7      886.1      864.0      810.7      747.3      706.2

CARBON MONOXIDE

     PPM BY VOLUME                 149.2     172.8      181.0      194.6      187.5      130.1      138.4      160.8      203.1      222.2
     LB. PER 1000 LB. OF FUEL     23.979    22.349     20.242     21.406     15.547      6.898      7.375      9.128     12.188     13.624
     WEIGHT FLOW, LB./HR.          2.662     2.883      2.996      3.618      3.164      1.954      2.037      2.368      2.919      3.086

UNBURNED HYDROCARBONS AS PPM CARBON

     PPM BY VOLUME                  43.5      37.1       27.8       22.9       12.7        2.1        3.0        3.0        5.4        5.4
     LB. PER 1000 LB. OF FUEL      3.992     2.744      1.775      1.442       .601       .064       .092       .098       .186       .190
     WEIGHT FLOW, LB./HR.           .443      .354       .263       .244       .122       .018       .025       .025       .045       .043

NITRIC OXIDE

     PPM BY VOLUME                   7.5       9.1       13.2       17.3       24.9       61.8       59.3       51.6       44.5       41.5
     LB. PER 1000 LB. OF FUEL      1.296     1.254      1.579      2.039      2.216      3.510      3.383      3.138      2.858      2.729
     WEIGHT FLOW, LB./HR.           .144      .162       .234       .345       .451       .994       .934       .814       .685       .618

NITROGEN DIOXIDE

     PPM BY VOLUME                  13.8      13.5       14.2       15.4       15.2        9.5        9.4       11.6       14.0       14.9
     LB. PER 1000 LB. OF FUEL      3.643     2.863      2.606      2.781      2.068       .824       .819      1.079      1.378      1.499
     WEIGHT FLOW, LB./HR.           .404      .369       .386       .470       .421       .233       .226       .280       .330       .340

TOTAL OXIDES OF NITROGEN AS NO2  (3)

     PPM BY VOLUME                  21.3      22.5       27.4       32.7       40.1       71.2       68.6       63.2       58.4       56.4
     LB. PER 1000 LB. OF FUEL      5.630     4.786      5.027      5.906      5.466      6.205      6.005      5.890      5.760      5.683
     WEIGHT FLOW, LB./HR.           .625      .617       .744       .998      1.112      1.757      1.659      1.528      1.380      1.287

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                         PROBE COMPARISON TEST
                                        PROBE 1-10 vs PROBE 11-20
                                EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
                                ********************************************
ENGINE   GTC85-90          S/N    P-5786    DATE OF TEST    5/18/71   TYPE OF FUEL        JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877    RATED SHP=    0.0    RATED EGT=1170.0 DEG.F    RATED SPEED= 40800.0
DEW PT.= 23.0     REL.HUMIDITY= 16.0 PERCENT     SPECIFIC HUMIDITY=  .00258    BAROMETRIC PRESSURE=28.79 IN HGA
                                         PROBE LOCATIONS 1-10                                  PROBE LOCATIONS 11-20
POWER SETTING NUMBER                  1         2         3         4         5   |      1         2         3         4         5
PERCENT MAX. CORRECTED POWER        0.0       0.0       0.0       0.0       0.0   |    0.0       0.0       0.0       0.0       0.0
CORRECTED SHAFT HP                  0.0       0.0       0.0       0.0       0.0   |    0.0       0.0       0.0       0.0       0.0
MEASURED SHAFT HP                   0.0       0.0       0.0       0.0       0.0   |    0.0       0.0       0.0       0.0       0.0
EXHAUST GAS TEMP., DEG.F          565.0     710.0     850.0    1000.0    1170.0   |  565.0     710.0     850.0    1000.0    1170.0
SHAFT SPEED, N1, RPM            41200.0   41100.0   40900.0   40800.0   40700.0   |41200.0   41100.0   40900.0   40800.0   40700.0
COMPRESSOR INLET TEMP.,DEG.F       78.0      80.0      80.0      85.0      92.0   |   84.0      86.0      87.0      90.0      92.0
COMPRESSOR DSCHG. PRES.,PSIA       51.7      50.2      48.7      46.8      40.2   |   51.7      50.0      48.3      46.8      39.7
CORRECTED BLEED FLOW, LB/MIN       0.00     43.41     68.80     88.33    109.76   |   0.00     44.52     68.59     89.19    108.44
CORRECTED FUEL FLOW , LB/HR       107.9     139.2     164.2     184.5     216.2   |  107.9     137.1     162.1     185.5     211.0
FA RATIO CALC. FROM EMISSION      .0075     .0101     .0123     .0148     .0181   |  .0071     .0097     .0119     .0143     .0166
EQUIVALENCE RATIO                  .109      .147      .179      .215      .263   |   .103      .141      .173      .209      .242
**************************************************SUMMARY OF REDUCED EMISSION DATA*********************************************
CARBON DIOXIDE

    PERCENT BY VOLUME              1.49      2.03      2.49      3.00      3.66   |   1.40      1.96      2.41      2.92      3.38
    LB. CO2 PER LB. OF FUEL        3.05      3.09      3.11      3.13      3.14   |   3.04      3.09      3.12      3.13      3.14
    WEIGHT FLOW, LB./HR.          329.2     430.6     511.4     577.7     679.4   |  329.4     424.2     505.2     581.4     663.4

CARBON MONOXIDE

    PPM BY VOLUME                 418.9     419.5     389.1     327.8     266.9   |  405.7     398.5     364.0     290.1     231.8
    LB. PER 1000 LB. OF FUEL     54.466    40.604    31.009    21.738    14.572   | 55.956    40.086    29.934    19.849    13.714
    WEIGHT FLOW, LB./HR.          5.877     5.652     5.092     4.011     3.150   |  6.038     5.496     4.852     3.682     2.894

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                 144.3      55.6      18.2       4.4       4.5   |  157.7      55.3      16.6       4.8       2.6
    LB. PER 1000 LB. OF FUEL     10.724     3.075      .830      .167      .141   | 12.434     3.179      .779      .188      .088
    WEIGHT FLOW, LB./HR.          1.157      .428      .136      .031      .030   |  1.342      .436      .126      .035      .018

NITRIC OXIDE

    PPM BY VOLUME                   3.5      11.3      20.2      30.3      43.6   |    7.0      17.2      27.3      37.3      44.2
    LB. PER 1000 LB. OF FUEL       .483     1.172     1.728     2.155     2.550   |  1.031     1.856     2.402     2.735     2.804
    WEIGHT FLOW, LB./HR.           .052      .163      .284      .398      .551   |   .111      .254      .389      .507      .592

NITROGEN DIOXIDE

    PPM BY VOLUME                  11.8      13.7      13.3      11.5       8.5   |    9.0       8.9       7.9       5.9       6.3
    LB. PER 1000 LB. OF FUEL      2.520     2.179     1.742     1.258      .766   |  2.036     1.469     1.065      .660      .610
    WEIGHT FLOW, LB./HR.           .272      .303      .286      .232      .166   |   .220      .201      .173      .122      .129

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                  15.3      25.0      33.5      41.9      52.1   |   16.0      26.1      35.1      43.2      50.5
    LB. PER 1000 LB. OF FUEL      3.260     3.976     4.391     4.562     4.675   |  3.618     4.315     4.748     4.853     4.909
    WEIGHT FLOW, LB./HR.           .352      .553      .721      .842     1.011   |   .390      .592      .770      .900     1.036

***** NOTES *****
    1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
    2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
    3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                        EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTC85-90-B       S/N   P-24504     DATE OF TEST      3/5/71   TYPE OF FUEL        JP4

FUEL H/C=1.990    STOICHIOMETRIC F/A=  .06806    RATED SHP=    0.0    RATED EGT=1175.0 DEG.F    RATED SPEED= 40800.0
DEW PT.= 33.5     REL.HUMIDITY= 23.0 PERCENT     SPECIFIC HUMIDITY=  .00418    BAROMETRIC PRESSURE=28.54 IN HGA

POWER SETTING NUMBER                  1          2          3          4          5
PERCENT MAX. CORRECTED POWER        0.0        0.0        0.0        0.0        0.0
CORRECTED SHAFT HP                  0.0        0.0        0.0        0.0        0.0
MEASURED SHAFT HP                   0.0        0.0        0.0        0.0        0.0
EXHAUST GAS TEMP., DEG.F          545.0      675.0      825.0      975.0     1125.0
SHAFT SPEED, N1, RPM            40850.0    40760.0    40660.0    40580.0    40450.0
COMPRESSOR INLET TEMP.,DEG.F       77.0       76.0       81.0       82.0       77.0
COMPRESSOR DSCHG. PRES.,PSIA       53.5       52.5       51.2       50.0       49.3
CORRECTED BLEED FLOW, LB/MIN       0.00      31.76      62.87      83.95     101.34
CORRECTED FUEL FLOW , LB/HR         0.0        0.0        0.0        0.0        0.0
FA RATIO CALC. FROM EMISSION      .0065      .0084      .0109      .0134      .0170
EQUIVALENCE RATIO                  .096       .129       .160       .197       .250
*********************************************SUMMARY OF REDUCED EMISSION DATA************************************************
CARBON DIOXIDE

     PERCENT BY VOLUME             1.30       1.75       2.17       2.68       3.41
     LB. CO2 PER LB. OF FUEL       3.05       3.06       3.06       3.08       3.10
     WEIGHT FLOW, LB./HR.           0.0        0.0        0.0        0.0        0.0

CARBON MONOXIDE

     PPM BY VOLUME                341.5      429.9      501.9      498.0      419.5
     LB. PER 1000 LB. OF FUEL    50.806     47.753     45.005     36.410     24.288
     WEIGHT FLOW, LB./HR.         0.000      0.000      0.000      0.000      0.000

UNBURNED HYDROCARBONS AS PPM CARBON

     PPM BY VOLUME                 58.0  [illegible]6.8       36.9       24.5        6.3
     LB. PER 1000 LB. OF FUEL     4.931      2.972      1.889      1.023       .208
     WEIGHT FLOW, LB./HR.         0.000      0.000      0.000      0.000      0.000

NITRIC OXIDE

     PPM BY VOLUME                  3.1        6.2       12.7       20.7       30.6
     LB. PER 1000 LB. OF FUEL      .497       .743      1.219      1.625      1.899
     WEIGHT FLOW, LB./HR.         0.000      0.000      0.000      0.000      0.000

NITROGEN DIOXIDE

     PPM BY VOLUME                 12.9       14.3       15.3       13.7       12.6
     LB. PER 1000 LB. OF FUEL     3.161      2.618      2.247      1.645      1.197
     WEIGHT FLOW, LB./HR.         0.000      0.000      0.000      0.000      0.000

TOTAL OXIDES OF NITROGEN AS NO2  (3)

     PPM BY VOLUME                 16.1       20.6       27.9       34.4       43.2
     LB. PER 1000 LB. OF FUEL     3.924      3.757      4.115      4.136      4.108
     WEIGHT FLOW, LB./HR.         0.000      0.000      0.000      0.000      0.000

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                                                     PROBE COMPARISON TEST

                                                          EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTC85-90-B        S/NP- 24376        DATE OF TEST   3/16/71      TYPE OF FUEL       JP-5

FUEL H/C=1.924    STOICHIOMETRIC F/A=  .06843    RATED SHP=    0.0    RATED EGT=1165.0 DEG.F     RATED SPEED= 40500.0
DEW PT.= 36.0     REL.HUMIDITY=  9.0 PERCENT     SPECIFIC HUMIDITY=  .00461     BAROMETRIC PRESSURE=28.70 IN HGA
                                                   PROBE LOCATIONS 1-10                                                PROBE LOCATIONS 11-20
POWER SETTING NUMBER                      1           2           3           4           5    |     1           2           3           4           5
PERCENT MAX. CORRECTED POWER            0.0         0.0         0.0         0.0         0.0    |   0.0         0.0         0.0         0.0         0.0
CORRECTED SHAFT HP                      0.0         0.0         0.0         0.0         0.0    |   0.0         0.0         0.0         0.0         0.0
MEASURED SHAFT HP                       0.0         0.0         0.0         0.0         0.0    |   0.0         0.0         0.0         0.0         0.0
EXHAUST GAS TEMP.. DEG.F              602.0       745.0       900.0      1052.0      1170.0    |   602.0       750.0       900.0      1050.0      1167.0
SHAFT SPEED. N1. RPM                41200.0     41100.0     40800.0     40700.0     40500.0    | 41300.0     41100.0     40800.0     40600.0     40500.0
COMPRESSOR INLET TEMP..DEG.F          109.0       107.0       108.0       108.0       108.0    |   107.0       108.0       109.0       108.0       108.0
COMPRESSOR DSCHG. PRES..PSIA                       49.2        47.3        45.8        29.3    |                49.2        47.5        46.0        29.3
CORRECTED BLEED FLOW. LB/MIN           0.00       35.98       63.40       86.05      101.07    |    0.00       36.25       63.64       86.34      101.21
CORRECTED FUEL FLOW . LB/HR             0.0        -0.0        -0.0        -0.0        -0.0    |   101.0       127.0       157.0       179.0       198.0
FA RATIO CALC. FROM EMISSION          .0073       .0096       .0119       .0145       .0168    |   .0073       .0095       .0119       .0148       .0171
EQUIVALENCE RATIO                      .107        .141        .173        .212        .245    |    .107        .139        .174        .217        .250
***********************************************SUMMARY OF REDUCED EMISSION DATA***********************************************************
CARBON DIOXIDE

   PERCENT BY VOLUME                   1.47        1.93        2.38        2.93        3.38    |    1.47        1.90        2.39        2.99        3.45
   LB. CO2 PER LB. OF FUEL             3.07        3.08        3.09        3.11        3.12    |    3.07        3.08        3.09        3.11        3.12
   WEIGHT FLOW. LB./HR.                 0.0         0.0         0.0         0.0         0.0    |   310.1       390.8       484.9       556.2       617.7

CARBON MONOXIDE

   PPM BY VOLUME                      381.6       461.1       494.6       438.8       385.5    |   398.5       457.9       500.3       448.5       381.6
   LB. PER 1000 LB. OF FUEL          50.673      45.736      40.814      29.646      22.651    |  53.130      47.134      41.110      29.707      21.977
   WEIGHT FLOW. LB./HR.               0.000       0.000       0.000       0.000       0.000    |   5.366       5.986       6.454       5.318       4.351

UNBURNED HYDROCARBONS AS PPM CARBON

   PPM BY VOLUME                       22.7        11.1         4.5          .6          .5    |     2.7]        15.3         8.6         1.8          .8
   LB. PER 1000 LB. OF FUEL           1.721        .645        .214        .023        .016    |    .205]X 10    .903        .404        .069        .026
   WEIGHT FLOW. LB./HR.               0.000       0.000       0.000       0.000       0.000    |    .021]        .115        .063        .012        .005

NITRIC OXIDE

   PPM BY VOLUME                        8.4        12.7        17.3        25.2        34.0    |    13.6        17.8        25.3        34.1        39.8
   LB. PER 1000 LB. OF FUEL           1.195       1.381       1.528       1.827       2.138    |   1.938       1.962       2.227       2.423       2.457
   WEIGHT FLOW. LB./HR.               0.000       0.000       0.000       0.000       0.000    |    .196        .249        .350        .434        .486

NITROGEN DIOXIDE

   PPM BY VOLUME                        8.1        11.2        11.9        11.5         9.4    |     4.5         5.4         4.3         2.6         3.6
   LB. PER 1000 LB. OF FUEL           1.766       1.860       1.612       1.273        .911    |    .989        .914        .580        .280        .345
   WEIGHT FLOW. LB./HR.               0.000       0.000       0.000       0.000       0.000    |    .100        .116        .091        .050        .068

TOTAL OXIDES OF NITROGEN AS NO2  (3)

   PPM BY VOLUME                       16.5        23.9        29.2        36.7        43.4    |    18.1        23.2        29.6        36.7        43.5
   LB. PER 1000 LB. OF FUEL           3.597       3.976       3.954       4.074       4.189    |   3.961       3.922       3.994       3.995       4.112
   WEIGHT FLOW. LB./HR.               0.000       0.000       0.000       0.000       0.000    |    .400        .498        .627        .715        .814

***** NOTES *****
      1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
      2.EQUIVALENCE RATIO CALCULATED FROM CO2.CO. AND HC DATA AND FUEL COMPOSITION.
      3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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GROUP 4

LARGE AUXILIARY POWER UNITS

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                                                        PROBE COMPARISON TEST
                                              EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTC85-90-B       S/NP- 24376      DATE OF TEST   9/15/71    TYPE OF FUEL       JP-5

FUEL H/C=1.928     STOICHIOMETRIC F/A=  .06843    RATED SHP=    0.0     RATED EGT=1165.0 DEG.F     RATED SPEED= 40500.0
DEW PT.= 36.0      REL.HUMIDITY=  9.0 PERCENT     SPECIFIC HUMIDITY=  .00461     BAROMETRIC PRESSURE=28.70 IN HGA
                                                 12-POINT FIXED PROBE                      12-POINT MOVEABLE PROBE  (LOCATIONS 1-20)
 POWER SETTING NUMBER                1         2         3         4         5    |     1         2         3         4         5
PERCENT MAX, CORRECTED POWER       0.0       0.0       0.0       0.0       0.0    |    0.0       0.0       0.0       0.0       0.0
CORRECTED SHAFT HP                 0.0       0.0       0.0       0.0       0.0    |    0.0       0.0       0.0       0.0       0.0
MEASURED SHAFT HP                  0.0       0.0       0.0       0.0       0.0    |    0.0       0.0       0.0       0.0       0.0
EXHAUST GAS TEMP., DEG.F         605.0     742.0     900.0    1045.0    1156.0    |  602.0     750.0     900.0    1050.0    1167.0
SHAFT SPEED, N1, RPM           41300.0   41100.0   40900.0   40700.0   40500.0    |41300.0   41100.0   40800.0   40600.0   40500.0
COMPRESSOR INLET TEMP.,DEG.F     104.0     106.0     105.0     105.0     105.0    |  107.0     108.0     109.0     108.0     108.0
COMPRESSOR DSCHG. PRES.,PSIA      51.1      49.4      48.0      46.5      43.6    |   14.1      49.2      47.5      46.0      29.3
CORRECTED BLEED FLOW, LB/MIN      0.00     35.86     62.40     83.63     98.12    |   0.00     36.25     63.64     86.34    101.21
CORRECTED FUEL FLOW , LB/HR      101.5     127.0     155.0     179.0     198.0    |  101.0     127.0     157.0     179.0     198.0
FA RATIO CALC. FROM EMISSION     .0072     .0094     .0118     .0142     .0167    |  .0073     .0095     .0119     .0148     .0171
EQUIVALENCE RATIO                 .106      .138      .173      .208      .245    |   .107      .139      .174      .217      .250
*******************************************SUMMARY OF REDUCED EMISSION DATA************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME             1.45      1.89      2.38      2.87      3.37    |   1.47      1.91      2.39      2.96      3.42
    LB. CO2 PER LB. OF FUEL       3.07      3.09      3.09      3.10      3.12    |
    WEIGHT FLOW, LB./HR.         311.8     391.0     478.8     555.7     617.0    |

CARBON MONOXIDE

    PPM BY VOLUME                384.0     462.3     488.9     451.6     405.4    |  390.0     459.5     497.5     443.7     393.5
    LB. PER 1000 LB. OF FUEL    51.758    47.817    40.444    31.139    23.860    |
    WEIGHT FLOW, LB./HR.         5.253     6.073     6.269     5.574     4.724    |

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                  3.0]      1.8]     12.8       5.6       5.6    |   24.8      13.5       6.5       1.2      0.65
    LB. PER 1000 LB. OF FUEL      .233]X 10 .107]X 10 .607      .220      .188    |
    WEIGHT FLOW, LB./HR.          .024]     .014]     .094      .039      .037    |

NITRIC OXIDE

    PPM BY VOLUME                 10.6      17.6      18.1      25.2      30.9    |   11.0      15.3      21.3      29.7      36.9
    LB. PER 1000 LB. OF FUEL     1.528     1.954     1.607     1.861     1.951    |
    WEIGHT FLOW, LB./HR.          .155      .248      .249      .333      .386    |

NITROGEN DIOXIDE

    PPM BY VOLUME                  6.0       4.8      10.1     -21.7]      8.9    |    6.3       8.3       8.1       6.6       6.5
    LB. PER 1000 LB. OF FUEL     1.338      .822     1.369    -2.454]?    .857    |
    WEIGHT FLOW, LB./HR.          .136      .104      .212     -.439]     .170    |

TOTAL OXIDES OF NITROGEN AS NO2  (3)

    PPM BY VOLUME                 16.6      22.5      28.2       3.5]     39.8    |   17.3      23.5      29.4      36.7      43.4
    LB. PER 1000 LB. OF FUEL     3.681     3.819     3.834      .399]X 10 3.848   |
    WEIGHT FLOW, LB./HR.          .374      .485      .594      .072]     .762    |

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM.CO2.CO. AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                  EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP660-4        S/N  P -37596    DATE OF TEST    5/26/71   TYPE OF FUEL        JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877    RATED SHP=  300.0    RATED EGT=1215.0 DEG.F    RATED SPEED= 20000.0
DEW PT.= 31.0     REL.HUMIDITY= 15.0 PERCENT     SPECIFIC HUMIDITY=  .00373    BAROMETRIC PRESSURE=28.69 IN HGA
                                         SHP ONLY, SURGE VALVE OPEN                          COMBINATION SHP/BLEED LOADING
POWER SETTING NUMBER                  1          6         11         16         20   |    22         19         15         10          5          3
PERCENT MAX. CORRECTED POWER        0.0       25.4       50.8       76.1      102.2   |   102.2       76.8       50.7       25.3        0.0        0.0
CORRECTED SHAFT HP                  0.0       76.1      152.3      228.2      306.5   |   306.6      230.3      152.1       75.8        0.0        0.0
MEASURED SHAFT HP                   0.0       74.9      150.1      224.9      302.3   |   302.4      227.3      150.1       74.9        0.0        0.0
EXHAUST GAS TEMP., DEG.F          681.0      723.0      763.0      801.0      949.0   |  1209.0     1202.0     1194.0     1187.0     1180.0      953.0
SHAFT SPEED, N1, RPM            20020.0    20010.0    20010.0    20020.0    20010.0   | 20020.0    20010.0    20010.0    20010.0    20020.0    20010.0
COMPRESSOR INLET TEMP.,DEG.F       86.0       87.0       88.0       88.0       89.0   |    89.0       90.0       90.0       92.0       92.0       95.0
COMPRESSOR DSCHG. PRES.,PSIA       55.1       55.7       56.2       56.8       57.1   |    51.7       50.5       49.4       48.0       46.9       49.6
CORRECTED BLEED FLOW, LB/MIN       0.00       0.00       0.00       0.00       0.00   |  468.46     483.82     504.98     524.23     541.12     432.06
CORRECTED FUEL FLOW , LB/HR       596.0      641.5      686.0      725.0      773.0   |   970.0      942.0      914.0      885.0      872.0      757.0
FA RATIO CALC. FROM EMISSION      .0080      .0084      .0093      .0097      .0105   |   .0169      .0164      .0162      .0164      .0159      .0127
EQUIVALENCE RATIO                  .116       .122       .135       .140       .153   |    .246       .238       .236       .238       .232       .184
*****************************************************SUMMARY OF REDUCED EMISSION DATA*****************************************************
CARBON DIOXIDE

   PERCENT BY VOLUME               1.63       1.72       1.90       1.98       2.16   |    3.45       3.34       3.30       3.34       3.25       2.59
   LB. CO2 PER LB. OF FUEL         3.14       3.14       3.14       3.15       3.15   |    3.15       3.15       3.15       3.15       3.15       3.15
   WEIGHT FLOW, LB./HR.          1872.1     2016.3     2157.3     2281.2     2432.8   |  3057.0     2968.0     2880.1     2787.7     2746.3     2383.3

CARBON MONOXIDE

   PPM BY VOLUME                  116.7      114.0      117.2      112.5      117.8   |   146.6      146.7      143.5      154.1      156.8      129.4
   LB. PER 1000 LB. OF FUEL      14.302     13.255     12.341     11.384     10.945   |   8.529      8.817      8.706      9.260      9.681     10.016
   WEIGHT FLOW, LB./HR.           8.524      8.503      8.466      8.254      8.461   |   8.274      8.306      7.958      8.195      8.442      7.582

UNBURNED HYDROCARBONS AS PPM CARBON

   PPM BY VOLUME                   11.2        9.6        9.4        8.5        9.3   |     9.0       12.3       10.0       13.0       11.8       13.4
   LB. PER 1000 LB. OF FUEL        .785       .635       .568       .494       .491   |    .299       .421       .347       .448       .417       .592
   WEIGHT FLOW, LB./HR.            .468       .407       .389       .358       .380   |    .290       .397       .317       .396       .364       .448

NITRIC OXIDE

   PPM BY VOLUME                   18.4       20.6       22.3       24.6       27.2   |    49.3       48.7       46.5       47.6       45.1       34.3
   LB. PER 1000 LB. OF FUEL       2.412      2.564      2.514      2.661      2.710   |   3.074      3.133      3.026      3.068      2.983      2.846
   WEIGHT FLOW, LB./HR.           1.437      1.645      1.724      1.929      2.095   |   2.981      2.952      2.766      2.715      2.601      2.154

NITROGEN DIOXIDE

   PPM BY VOLUME                    5.2        5.4        5.9        5.8        6.1   |     8.8        8.2        8.5        7.9        8.5        6.9
   LB. PER 1000 LB. OF FUEL       1.043      1.039      1.018       .970       .937   |    .837       .805       .848       .780       .862       .883
   WEIGHT FLOW, LB./HR.            .622       .666       .698       .703       .724   |    .812       .758       .775       .690       .752       .668

TOTAL OXIDES OF NITROGEN AS NO2  (3)

   PPM BY VOLUME                   23.5       26.0       28.2       30.4       33.4   |    58.1       56.8       55.0       55.5       53.6       41.3
   LB. PER 1000 LB. OF FUEL       4.741      4.968      4.872      5.050      5.092   |   5.549      5.609      5.487      5.483      5.435      5.246
   WEIGHT FLOW, LB./HR.           2.826      3.187      3.342      3.661      3.936   |   5.383      5.283      5.015      4.853      4.740      3.971

***** NOTES *****
   1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
   2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
   3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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                                        EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY
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ENGINE   GTCP660-4          S/N   P-37705    DATE OF TEST    5/25/71    TYPE OF FUEL         JP5

FUEL H/C=1.877    STOICHIOMETRIC F/A=  .06877    RATED SHP=  300.0    RATED EGT=1215.0 DEG.F    RATED SPEED= 20000.0
DEW PT.= 27.0     REL.HUMIDITY=  9.0 PERCENT     SPECIFIC HUMIDITY=  .00313    BAROMETRIC PRESSURE=28.58 IN HGA
                                         SHP ONLY, SURGE VALVE OPEN                        COMBINED SHP/BLEED LOADING
POWER SETTING NUMBER                  1        6        11        16        20   |    22        19        15        10         5
PERCENT MAX. CORRECTED POWER        0.0     25.3      50.9      76.1     101.9   |  101.7      76.1      50.4      25.2       0.0
CORRECTED SHAFT HP                  0.0     75.8     152.8     228.3     305.7   |  305.0     228.3     151.2      75.5       0.0
MEASURED SHAFT HP                   0.0     74.9     151.1     225.9     302.3   |  302.1     225.9     149.8      74.9       0.0
EXHAUST GAS TEMP., DEG.F          681.0    719.0     767.0     800.0     823.0   | 1202.0    1192.0    1183.0    1172.0    1162.0
SHAFT SPEED, N1, RPM            20010.0  20010.0   20000.0   20000.0   20010.0   |20000.0   20000.0   20000.0   20000.0   20000.0
COMPRESSOR INLET TEMP.,DEG.F       96.0     96.0      96.0      97.0      96.0   |   98.0      97.0      98.0     100.0      99.0
COMPRESSOR DSCHG. PRES.,PSIA       54.1     54.7      55.3      56.0      56.6   |   51.0      49.9      48.7      47.3      46.0
CORRECTED BLEED FLOW, LB/MIN       0.00     0.00      0.00      0.00      0.00   | 496.22    513.21    531.06    555.03    571.89
CORRECTED FUEL FLOW , LB/HR       596.0    636.5     685.0     723.0     757.0   |  962.0     932.0     907.0     885.0     857.0
FA RATIO CALC. FROM EMISSION      .0077    .0082     .0090     .0096     .0101   |  .0159     .0162     .0163     .0167     .0164
EQUIVALENCE RATIO                  .112     .119      .131      .139      .146   |   .231      .235      .237      .242      .239
******************************************SUMMARY OF REDUCED EMISSION DATA**************************************************
CARBON DIOXIDE

    PERCENT BY VOLUME              1.58     1.68      1.85      1.96      2.06   |   3.23      3.30      3.32      3.39      3.34
    LB. CO2 PER LB. OF FUEL        3.15     3.15      3.15      3.15      3.15   |   3.15      3.15      3.15      3.15      3.14
    WEIGHT FLOW, LB./HR.         1875.1   2004.2    2155.0    2277.1    2382.3   | 3028.4    2932.6    2854.8    2783.6    2695.2

CARBON MONOXIDE

    PPM BY VOLUME                  77.1     80.4      87.4      92.8     103.8   |  167.5     174.2     177.1     191.4     197.3
    LB. PER 1000 LB. OF FUEL      9.761    9.569     9.448     9.480    10.073   | 10.380    10.578    10.690    11.308    11.833
    WEIGHT FLOW, LB./HR.          5.818    6.091     6.472     6.854     7.625   |  9.985     9.859     9.696    10.008    10.141

UNBURNED HYDROCARBONS AS PPM CARBON

    PPM BY VOLUME                  21.3     10.6      28.5       8.4      19.0   |   13.9      26.7      15.0      28.4      23.9
    LB. PER 1000 LB. OF FUEL      1.539     .718     1.760      .493     1.051   |   .491      .928      .518      .958      .818
    WEIGHT FLOW, LB./HR.           .917     .457     1.205      .356      .796   |   .473      .865      .470      .848      .701

NITRIC OXIDE

    PPM BY VOLUME                  17.0     20.5      23.1      25.2      27.4   |   51.0      50.4      53.9      56.8      54.6
    LB. PER 1000 LB. OF FUEL      2.312    2.610     2.670     2.761     2.853   |  3.386     3.277     3.488     3.599     3.511
    WEIGHT FLOW, LB./HR.          1.378    1.661     1.829     1.996     2.159   |  3.257     3.054     3.163     3.185     3.009

NITROGEN DIOXIDE

    PPM BY VOLUME                   3.8      4.8       5.2       5.9       6.3   |    9.3       9.9      10.9      11.0      11.4
    LB. PER 1000 LB. OF FUEL       .784     .934      .928      .987     1.001   |   .946      .983     1.081     1.064     1.124
    WEIGHT FLOW, LB./HR.           .467     .594      .635      .713      .758   |   .910      .916      .981      .941      .963

TOTAL OXIDES OF NITROGEN AS NO2   (3)

    PPM BY VOLUME                  20.8     25.2      28.3      31.1      33.7   |   60.3      60.2      64.8      67.8      66.0
    LB. PER 1000 LB. OF FUEL      4.329    4.935     5.022     5.220     5.375   |  6.138     6.007     6.428     6.581     6.507
    WEIGHT FLOW, LB./HR.          2.580    3.141     3.440     3.774     4.069   |  5.905     5.599     5.831     5.824     5.577

***** NOTES *****
     1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
     2.EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
     3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).
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EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY

ENGINE TSCP700-4 S/N P-90122 DATE OF TEST 5/25/71 TYPE OF FUEL JP5

FUEL H/C=1.877 STOICHIOMETRIC F/A= .06877 RATED SHP= 142.0 RATED EGT=1005.0 DEG.F RATED SPEED= 35350.0

DEW PT.= 31.0 REL.HUMIDITY= 18.0 PERCENT SPECIFIC HUMIDITY= .00373 BAROMETRIC PRESSURE=28.66 IN HGA

	IDLE	STANDBY MODE, SHP ONLY, SURGE VALVE OPEN					NORMAL MODE, COMBINATION LOAD					MES
POWER SETTING NUMBER	1	2	6	11	16	20	22	19	15	10	5	25
PERCENT MAX. CORRECTED POWER	0.0	0.0	25.7	50.1	73.6	99.9	99.7	73.5	50.0	25.5	0.0	0.0
CORRECTED SHAFT HP	0.0	0.0	36.5	71.1	104.5	141.9	141.6	104.4	71.0	36.2	0.0	0.0
MEASURED SHAFT HP	0.0	0.0	36.0	70.7	104.0	141.0	139.6	102.8	69.8	35.5	0.0	0.0
EXHAUST GAS TEMP., DEG.F	819.0	777.0	800.0	833.0	858.0	893.0	1005.0	1005.0	1005.0	1005.0	1005.0	887.0
SHAFT SPEED, N1, RPM	17680.0	24890.0	25000.0	25600.0	25900.0	26400.0	27300.0	27300.0	27300.0	27300.0	27300.0	28100.0
SHAFT SPEED, N2, RPM	35350.0	35950.0	35830.0	35800.0	35750.0	35690.0	35350.0	35350.0	35350.0	35350.0	35350.0	35350.0
COMPRESSOR INLET TEMP.,DEG.F	78.0	89.0	92.0	99.0	100.0	98.0	90.0	89.0	87.0	86.0	85.0	93.0
COMPRESSOR DSCHG. PRES.,PSIA	62.1	101.0	104.0	106.9	104.9	110.8	111.3	109.4	108.5	106.9	104.5	125.1
CORRECTED BLEED FLOW, LB/MIN	0.00	0.00	0.00	0.00	0.00	0.00	480.26	494.73	502.22	510.16	516.13	391.08
CORRECTED FUEL FLOW , LB/HR	225.0	337.0	37[illegible]	394.0	417.5	442.0	495.5	487.0	477.0	469.0	467.0	467.0
FA RATIO CALC. FROM EMISSION	.0113	.0113	.01[illegible]	.0122	.0127	.0135	.0152	.0152	.0152	.0153	.0155	.0130
EQUIVALENCE RATIO	.164	.165	.171	.177	.185	.196	.221	.221	.221	.222	.226	.189

**************SUMMARY OF REDUCED EMISSION DATA**************

	1	2	6	11	16	20	22	19	15	10	5	25
CARBON DIOXIDE												
PERCENT BY VOLUME	2.28	2.32	2.41	2.50	2.60	2.77	3.11	3.10	3.10	3.12	3.18	2.66
LB. CO2 PER LB. OF FUEL	3.11	3.15	3.15	3.15	3.15	3.16	3.16	3.16	3.16	3.16	3.16	3.15
WEIGHT FLOW, LB./HR.	699.7	1060.6	1168.7	1242.6	1317.0	1394.9	1564.1	1537.0	1505.7	1479.8	1474.5	1472.8
CARBON MONOXIDE												
PPM BY VOLUME	251.7	78.7	55.8	40.4	30.5	25.0	23.8	20.4	20.4	22.7	22.6	26.1
LB. PER 1000 LB. OF FUEL	21.810	6.790	4.630	3.244	2.351	1.812	1.537	1.323	1.323	1.458	1.431	1.972
WEIGHT FLOW, LB./HR.	4.907	2.288	1.718	1.278	.981	.801	.762	.644	.631	.684	.668	.921
UNBURNED HYDROCARBONS AS PPM CARBON												
PPM BY VOLUME	160.0	58.4	63.8	53.6	61.6	60.5	65.5	75.3	69.6	81.5	62.3	74.9
LB. PER 1000 LB. OF FUEL	7.925	2.881	3.030	2.458	2.717	2.511	2.421	2.786	2.574	2.995	2.253	3.234
WEIGHT FLOW, LB./HR.	1.783	.971	1.124	.968	1.134	1.110	1.200	1.357	1.228	1.405	1.052	1.510
NITRIC OXIDE												
PPM BY VOLUME	22.5	52.6	53.6	62.8	71.2	72.8	97.5	109.3	90.8	95.7	92.1	93.2
LB. PER 1000 LB. OF FUEL	2.093	4.860	4.766	5.396	5.887	5.663	6.754	7.578	6.297	6.594	6.237	7.548
WEIGHT FLOW, LB./HR.	.471	1.638	1.768	2.126	2.458	2.503	3.347	3.691	3.004	3.093	2.913	3.525
NITROGEN DIOXIDE												
PPM BY VOLUME	12.9	11.7	8.4	7.0	6.2	16.5	3.8	4.4	3.5	4.0	3.5	5.7
LB. PER 1000 LB. OF FUEL	1.833	1.658	1.149	.928	.781	1.965	.401	.468	.374	.425	.361	.703
WEIGHT FLOW, LB./HR.	.413	.559	.426	.366	.326	.868	.199	.228	.179	.199	.168	.328
TOTAL OXIDES OF NITROGEN AS NO2 (3)												
PPM BY VOLUME	35.4	64.3	62.0	69.8	77.4	89.3	101.3	113.7	94.3	99.7	95.5	98.9
LB. PER 1000 LB. OF FUEL	5.042	9.109	8.456	9.202	9.807	10.648	10.755	12.087	10.029	10.535	9.924	12.274
WEIGHT FLOW, LB./HR.	1.134	3.070	3.137	3.626	4.094	4.706	5.329	5.886	4.784	4.941	4.634	5.732

***** NOTES *****

1.ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
2.EQUIVALENCE RATIO CALCULATED FROM CO2.CO, AND HC DATA AND FUEL COMPOSITION.
3.TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).

EPA-AIRESEARCH EMISSION PROGRAM TEST SUMMARY

ENGINE TSCP700-4 S/N P-90123 DATE OF TEST 5/27/71 TYPE OF FUEL JP-5

FUEL H/C=1.877 STOICHIOMETRIC F/A= .06877 RATED SHP= 142.0 RATED EGT=1005.0 DEG.F RATED SPEED= 35350.0
DEW PT.= 33.0 REL.HUMIDITY= 18.0 PERCENT SPECIFIC HUMIDITY= .00406 BAROMETRIC PRESSURE=28.72 IN HGA

	IDLE	STANDBY MODE, SHP ONLY, SURGE VALVE OPEN					NORMAL MODE, COMBINATION LOAD					MES
POWER SETTING NUMBER	1	2	6	11	16	20	22	19	15	10	5	25
PERCENT MAX. CORRECTED POWER	0.0	0.0	24.5	48.5	73.3	99.6	99.8	73.5	49.9	25.5	0.0	0.0
CORRECTED SHAFT HP	0.0	0.0	34.8	68.9	104.0	141.5	141.8	104.4	70.9	36.2	0.0	0.0
MEASURED SHAFT HP	0.0	0.0	34.8	68.4	103.9	141.1	140.0	103.1	70.0	35.6	0.0	0.0
EXHAUST GAS TEMP., DEG.F	842.0	939.0	979.0	884.0	929.0	956.0	1005.0	1005.0	1005.0	1005.0	1005.0	908.0
SHAFT SPEED, N1, RPM	17650.0	28100.0	27800.0	23550.0	26270.0	26750.0	27300.0	27300.0	27300.0	27300.0	27340.0	28100.0
SHAFT SPEED, N2, RPM	35440.0	35000.0	34650.0	34650.0	35730.0	35720.0	35440.0	35440.0	35440.0	35440.0	35440.0	35440.0
COMPRESSOR INLET TEMP.,DEG.F	82.0	100.0	103.0	96.0	102.0	100.0	89.0	89.0	89.0	87.0	87.0	91.0
COMPRESSOR DSCHG. PRES.,PSIA	59.1	115.1	114.0	102.1	106.1	110.1	109.8	108.6	107.9	104.4	102.6	116.5
CORRECTED BLEED FLOW, LB/MIN	0.00	0.00	0.00	0.00	0.00	0.00	448.74	464.48	474.14	488.92	477.35	420.39
CORRECTED FUEL FLOW , LB/HR	228.0	481.0	482.0	409.0	436.0	469.0	497.0	489.0	481.0	471.0	460.0	474.0
FA RATIO CALC. FROM EMISSION	.0116	.0140	.0146	.0127	.0133	.0143	.0153	.0149	.0149	.0151	.0152	.0137
EQUIVALENCE RATIO	.168	.204	.212	.185	.193	.207	.223	.216	.217	.220	.221	.199

**********SUMMARY OF REDUCED EMISSION DATA**********

	IDLE 1	2	6	11	16	20	22	19	15	10	5	MES 25
CARBON DIOXIDE												
PERCENT BY VOLUME	2.35	2.88	2.99	2.61	2.73	2.92	3.14	3.04	3.06	3.09	3.11	2.81
LB. CO2 PER LB. OF FUEL	3.13	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16	3.16
WEIGHT FLOW, LB./HR.	713.8	1520.2	1522.1	1292.8	1377.2	1481.8	1571.1	1545.5	1520.2	1488.3	1452.1	1497.8
CARBON MONOXIDE												
PPM BY VOLUME	193.2	16.0	18.8	22.2	18.9	14.8	21.0	19.4	22.1	19.3	48.6	27.7
LB. PER 1000 LB. OF FUEL	16.351	1.117	1.266	1.715	1.391	1.018	1.345	1.279	1.457	1.257	3.141	1.981
WEIGHT FLOW, LB./HR.	3.728	.537	.610	.701	.607	.478	.668	.625	.781	.592	1.445	.939
UNBURNED HYDROCARBONS AS PPM CARBON												
PPM BY VOLUME	69.5	31.0	55.6	18.1	40.9	43.6	24.5	31.4	28.8	38.8	39.9	23.6
LB. PER 1000 LB. OF FUEL	3.361	1.238	2.137	.799	1.725	1.716	.895	1.186	1.085	1.442	1.471	.963
WEIGHT FLOW, LB./HR.	.766	.595	1.030	.327	.752	.805	.445	.580	.522	.679	.677	.457
NITRIC OXIDE												
PPM BY VOLUME	20.8	45.2	46.5	44.6	52.1	60.4	83.7	79.1	76.1	75.8	76.6	75.0
LB. PER 1000 LB. OF FUEL	1.890	3.385	3.353	3.685	4.117	4.452	5.742	5.601	5.368	5.277	5.296	5.748
WEIGHT FLOW, LB./HR.	.431	1.628	1.616	1.507	1.795	2.088	2.854	2.739	2.582	2.486	2.436	2.725
NITROGEN DIOXIDE												
PPM BY VOLUME	12.6	1.4	2.1	3.7	2.8	3.3	.4	3.4	3.6	3.4	3.2	4.1
LB. PER 1000 LB. OF FUEL	1.750	.156	.228	.465	.342	.370	.042	.366	.386	.362	.342	.485
WEIGHT FLOW, LB./HR.	.399	.075	.110	.190	.149	.173	.021	.179	.186	.171	.157	.230
TOTAL OXIDES OF NITROGEN AS NO2 (3)												
PPM BY VOLUME	33.4	46.5	48.6	48.3	54.9	63.7	84.1	82.5	79.7	79.2	79.8	79.1
LB. PER 1000 LB. OF FUEL	4.647	5.345	5.368	6.115	6.654	7.195	8.846	8.954	8.616	8.453	8.461	9.298
WEIGHT FLOW, LB./HR.	1.060	2.571	2.587	2.501	2.901	3.374	4.396	4.378	4.144	3.982	3.892	4.407

***** NOTES *****

1. ALL EMISSIONS CONCENTRATIONS CORRECTED TO CONCENTRATION IN WET EXHAUST FROM COMBUSTION WITH DRY AIR.
2. EQUIVALENCE RATIO CALCULATED FROM CO2,CO, AND HC DATA AND FUEL COMPOSITION.
3. TOTAL NITROGEN OXIDES CALCULATED USING NOX CONCENTRATION AND MOLECULAR WEIGHT OF NO2 (46.01).

APPENDIX C

MEASURED AND CALCULATED EMISSIONS PERFORMANCE PLOTTED AS A FUNCTION OF EQUIVALENCE RATIO

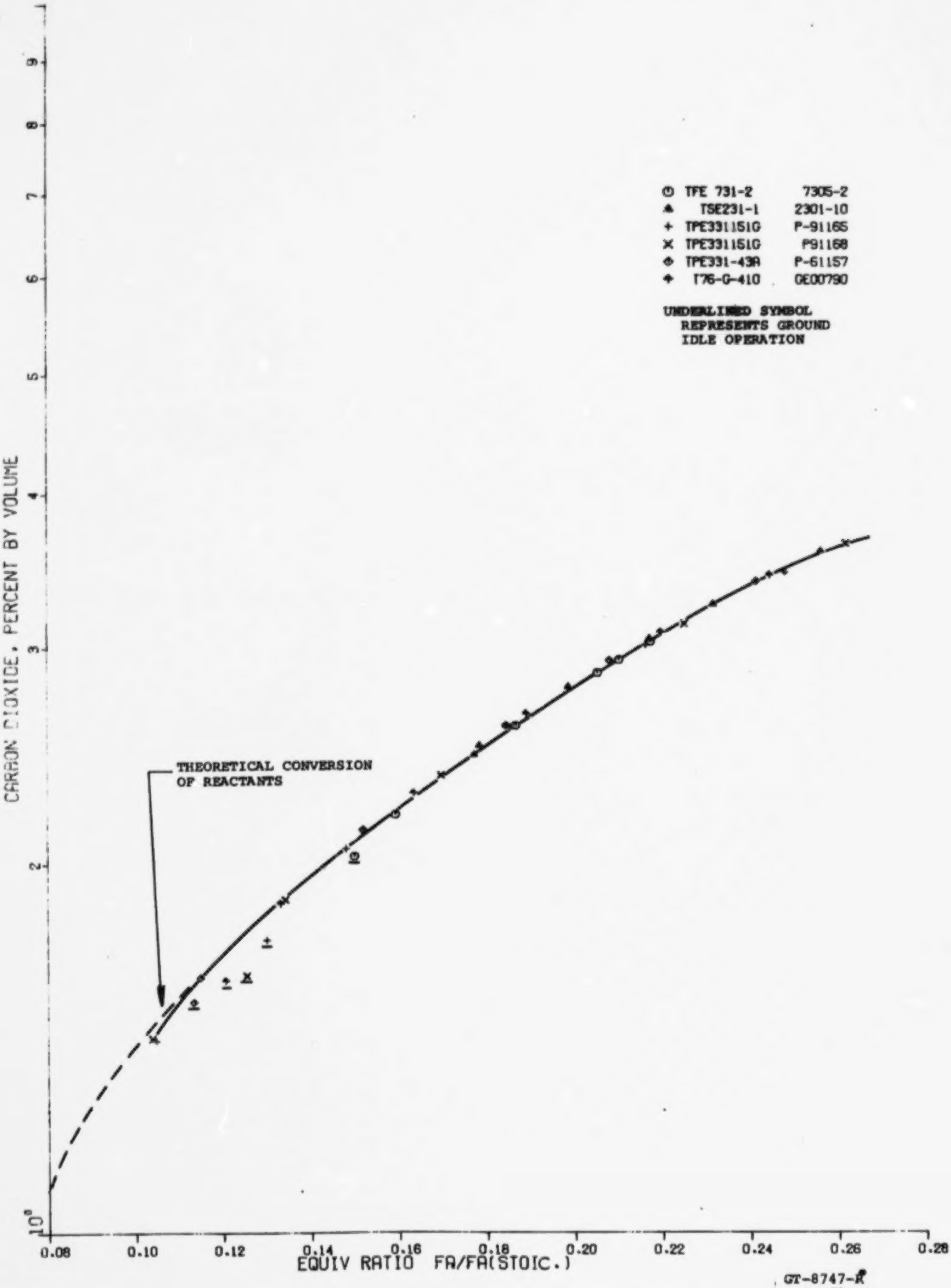
The curve index lists measured pollutant concentration in ppm, calculated emissions index and formation rate and the corresponding page number location for each.

CURVE INDEX

	Appendix C Page Numbers			
Measured and Calculated Performance	Group 1 Propulsion Units	Group 2 Small APUs	Group 3 Medium APUs	Group 4 Large APUs
CO_2				
% by volume	1	19	38	57
lb/lb fuel	2	20	39	58
lb/hr	3	21	40	59
CO				
ppm by volume	4	22	41	60
lb/1000 lb fuel	5	23	42	61
lb/hr	6	24	43	62
HC (hot)				
ppm by volume	7	25	44	63
lb/1000 lb fuel	8	26	45	64
lb/hr	9	27	46	65
NO				
ppm by volume	10	28	47	66
lb/1000 lb fuel	11	29	48	67
lb/hr	12	30	49	68
NO_x (as NO_2)				
ppm by volume	13	31	50	69
lb/1000 lb fuel	14	32	51	70
lb/hr	15	33	52	71
Corrected shaft horsepower	16	34	53	72
Exhaust gas temperature	17	35	54	73
Corrected bleed flow	--	36	55	74
Corrected fuel flow	18	37	56	75

GROUP 1

AIRCRAFT PROPULSION ENGINES



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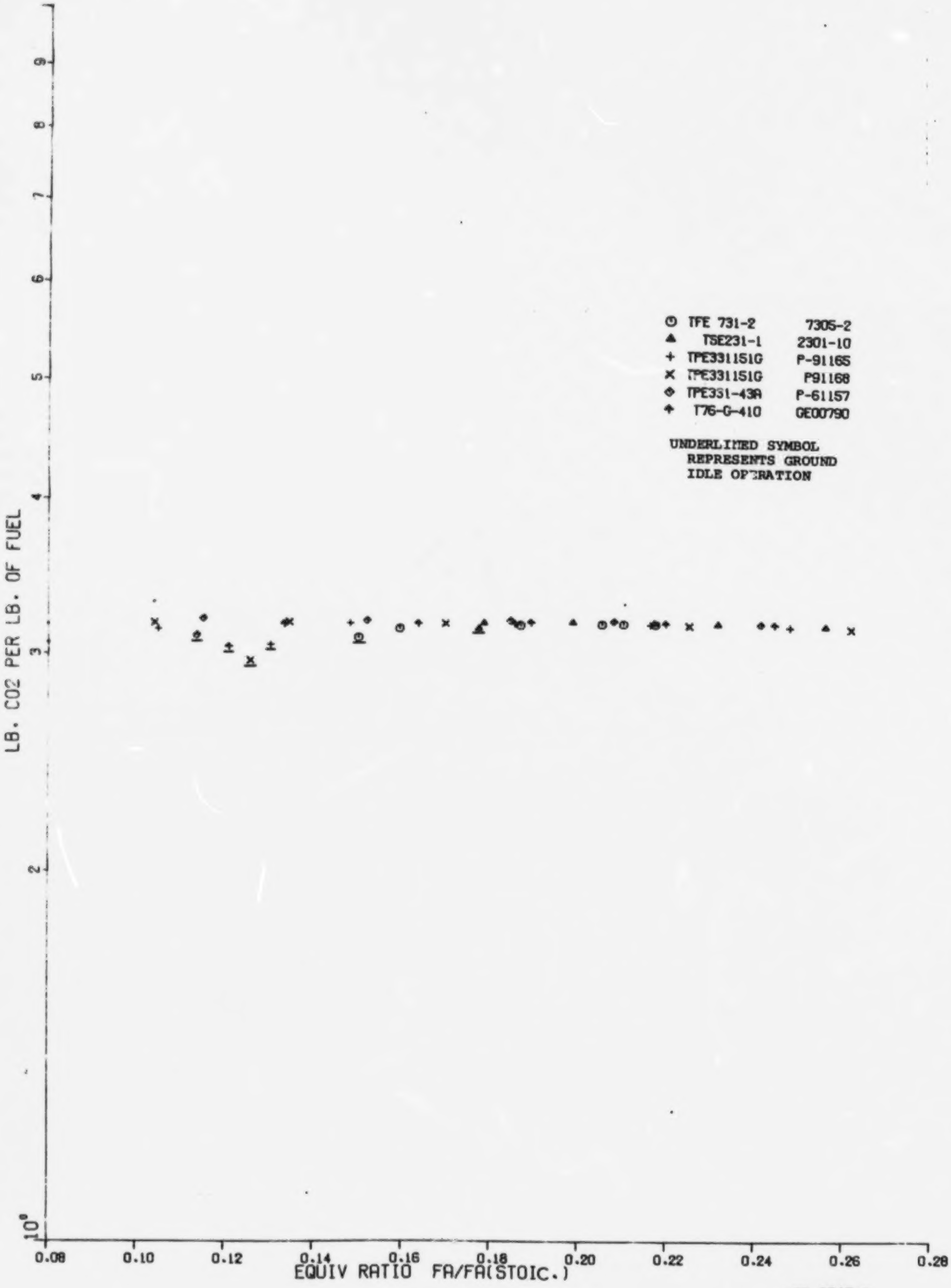

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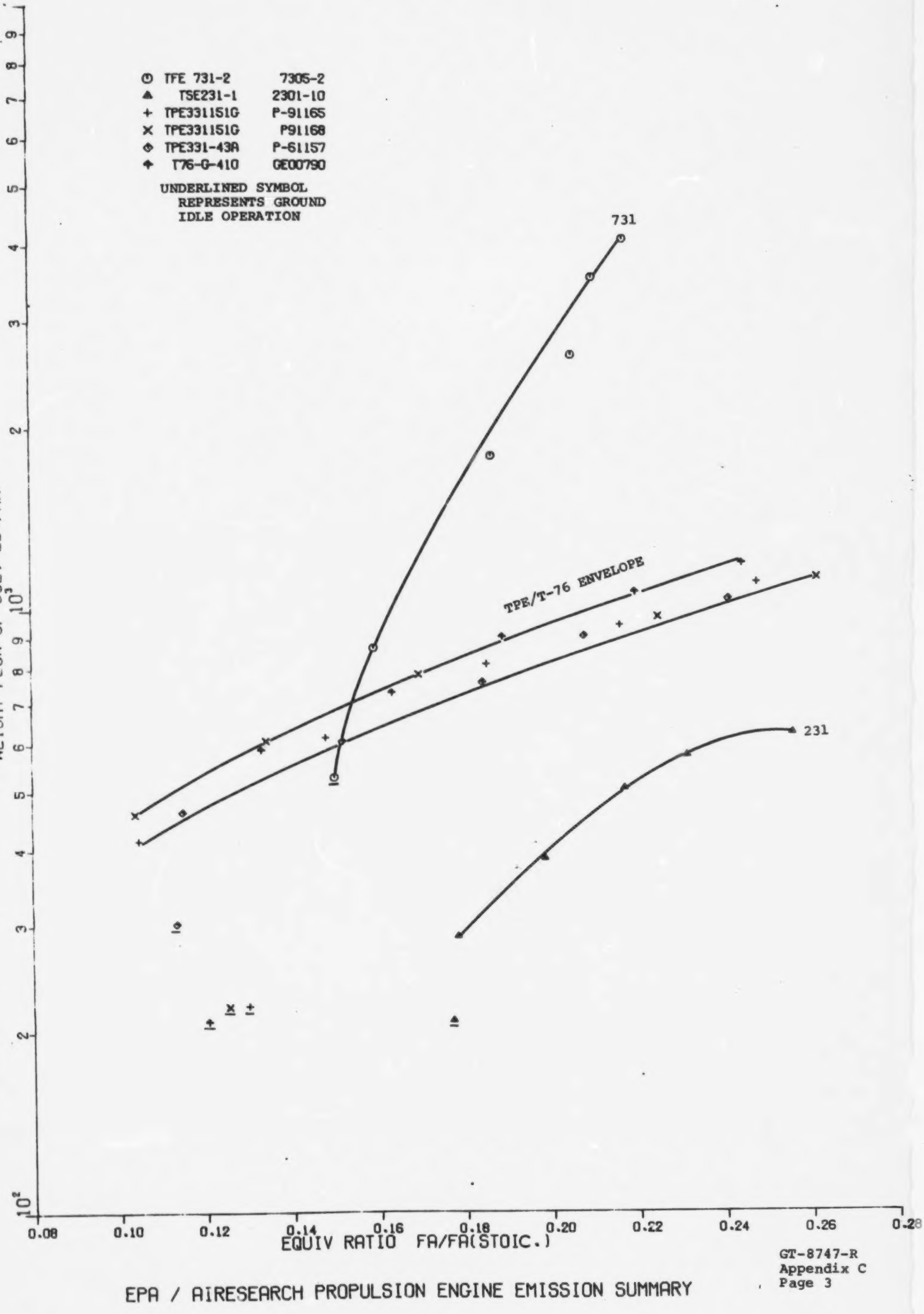

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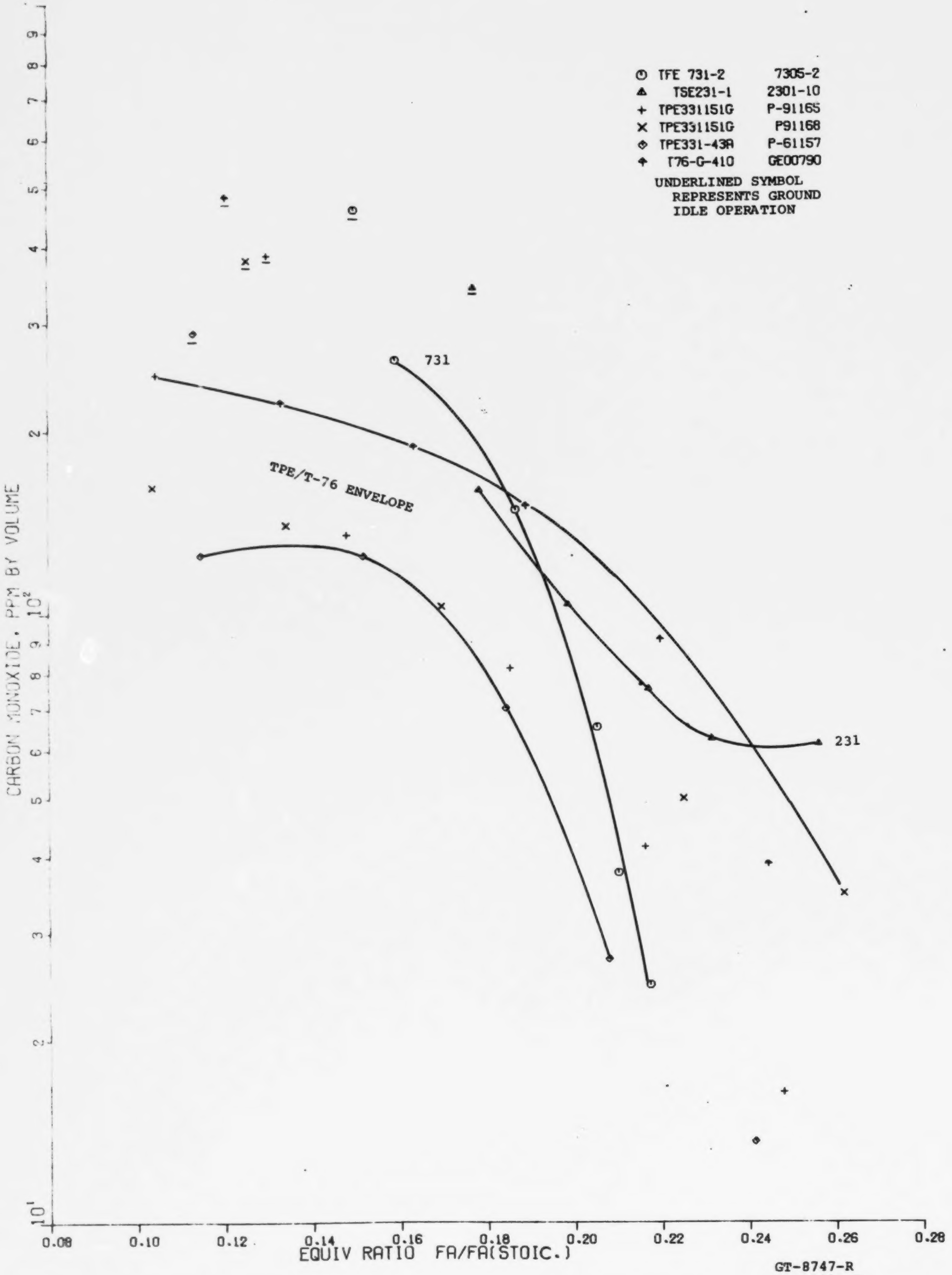

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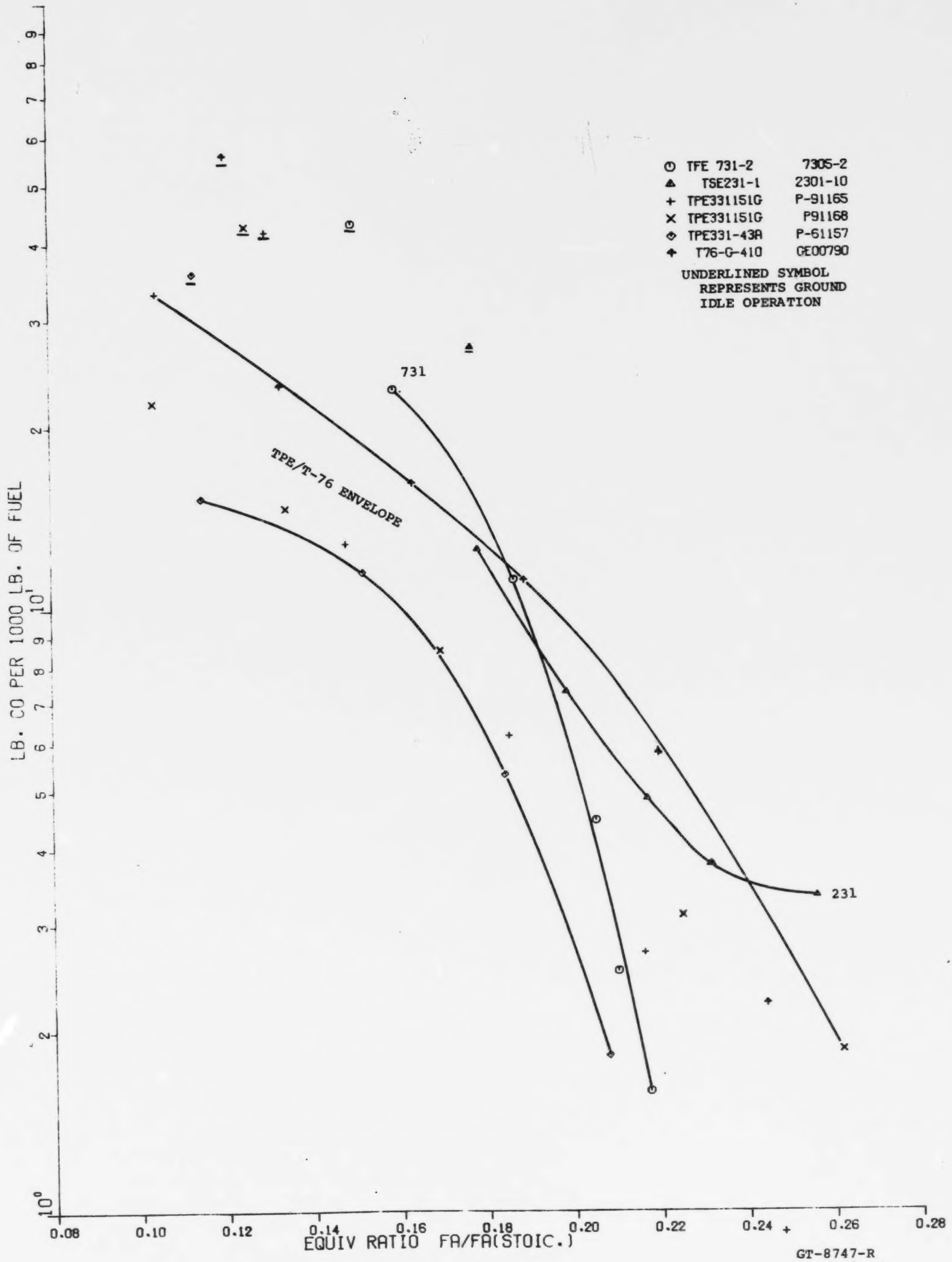

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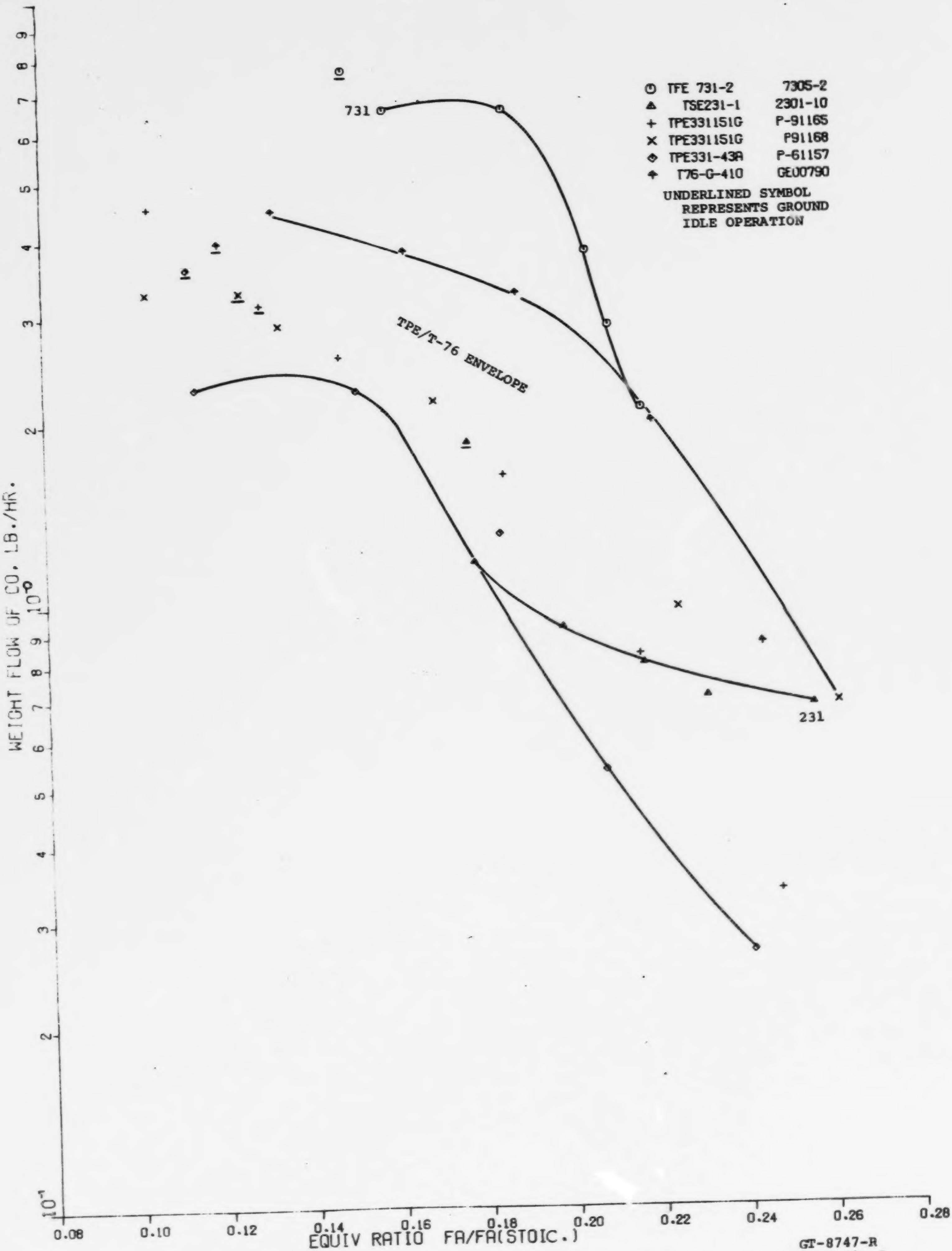

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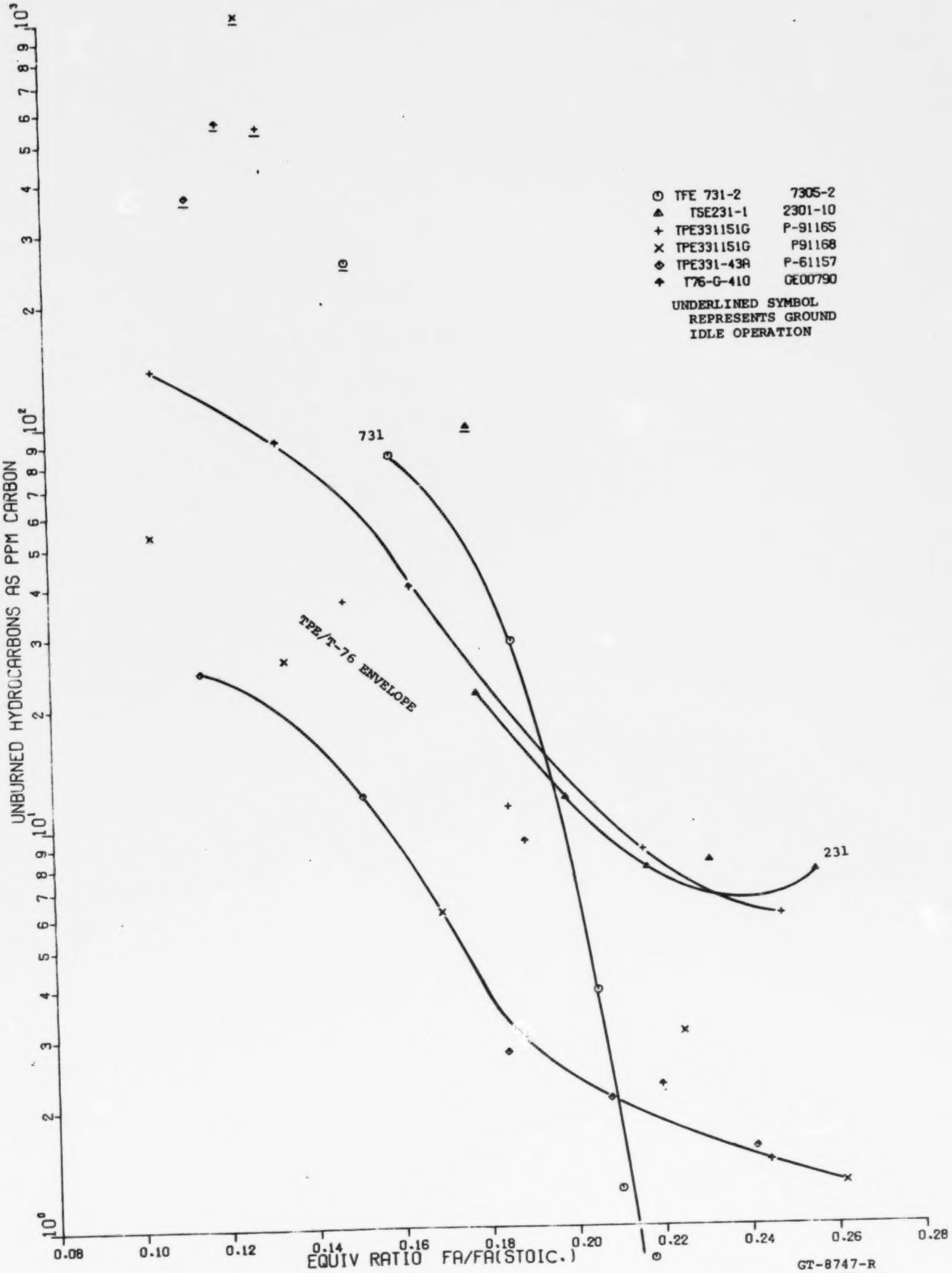

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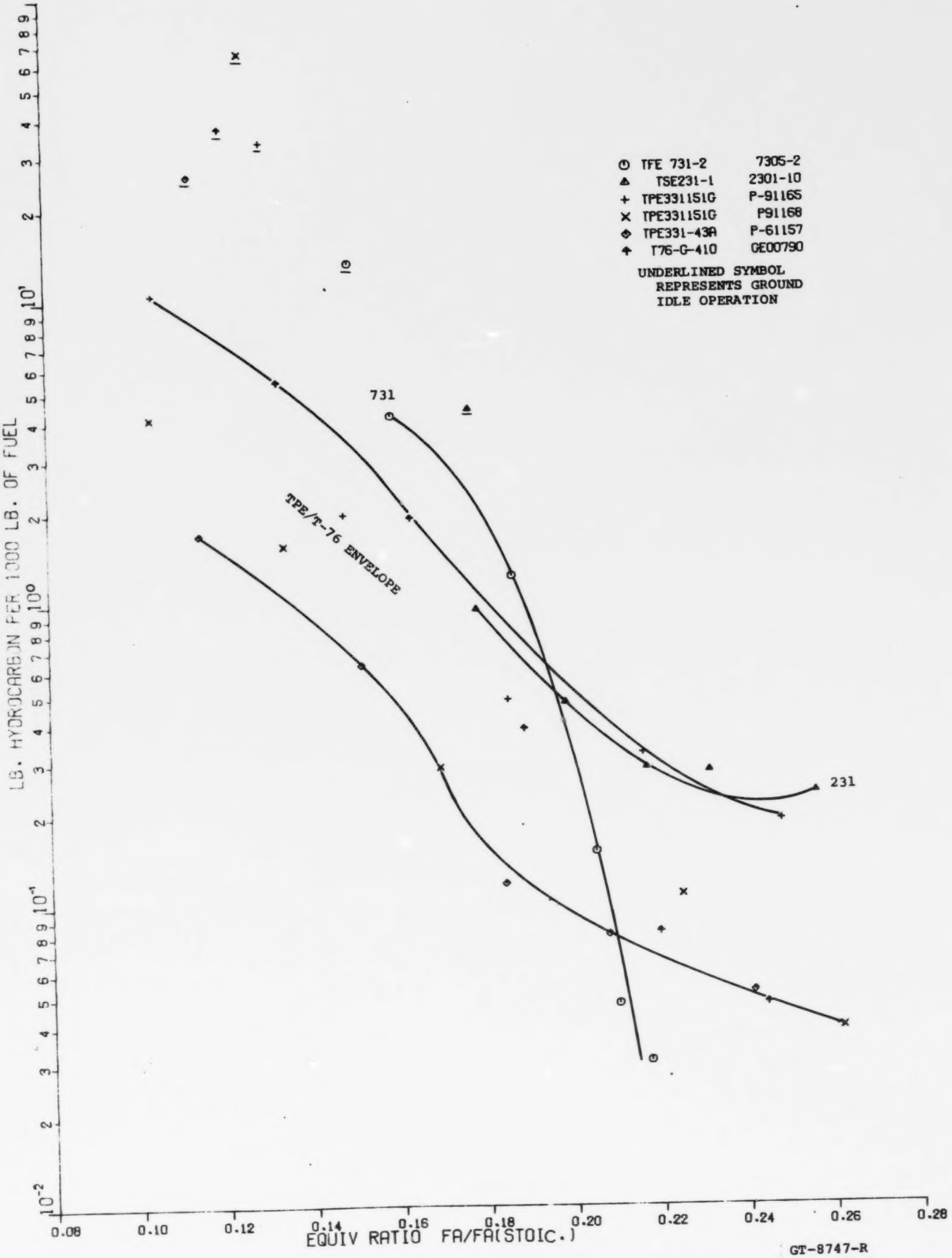

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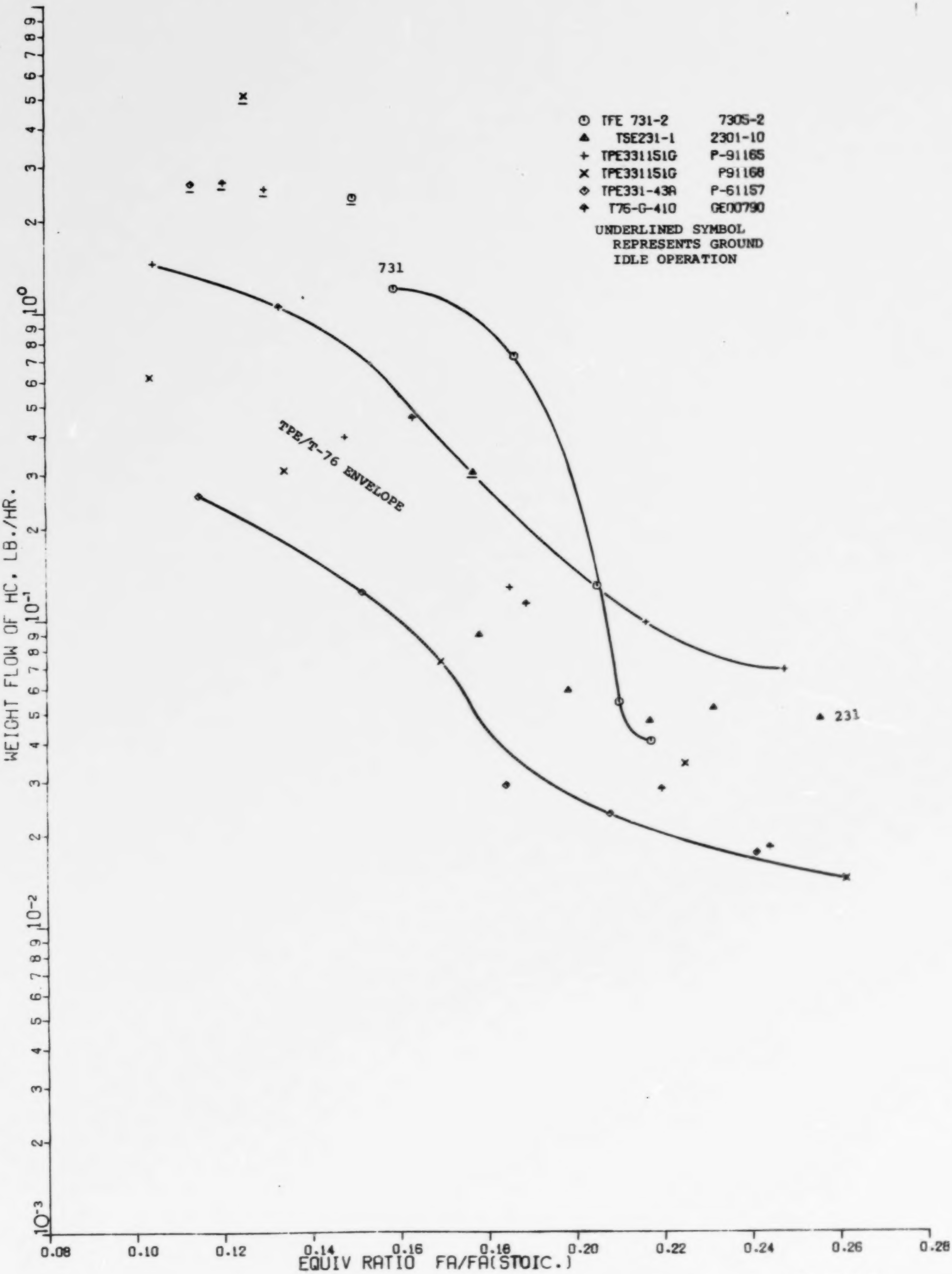

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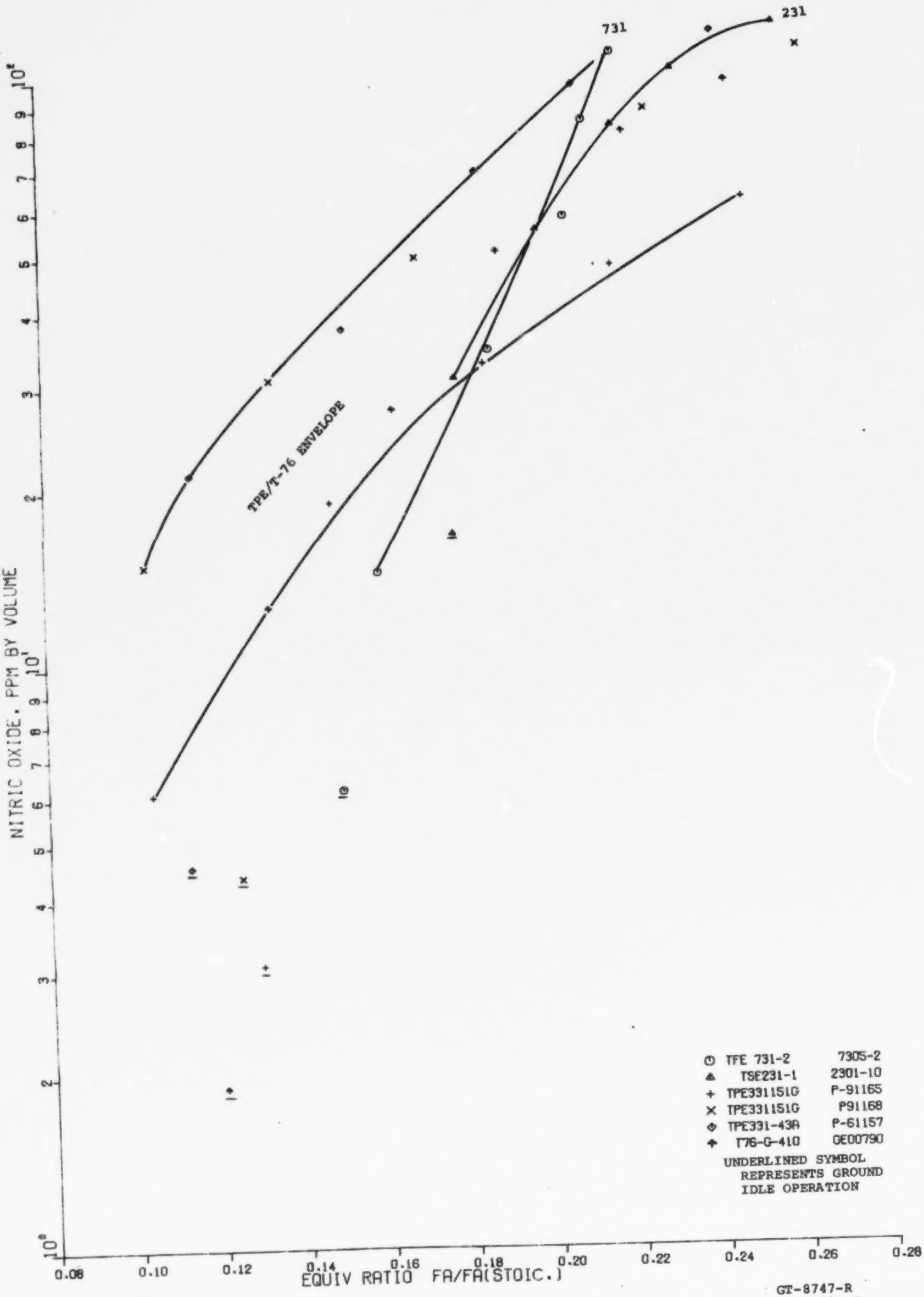

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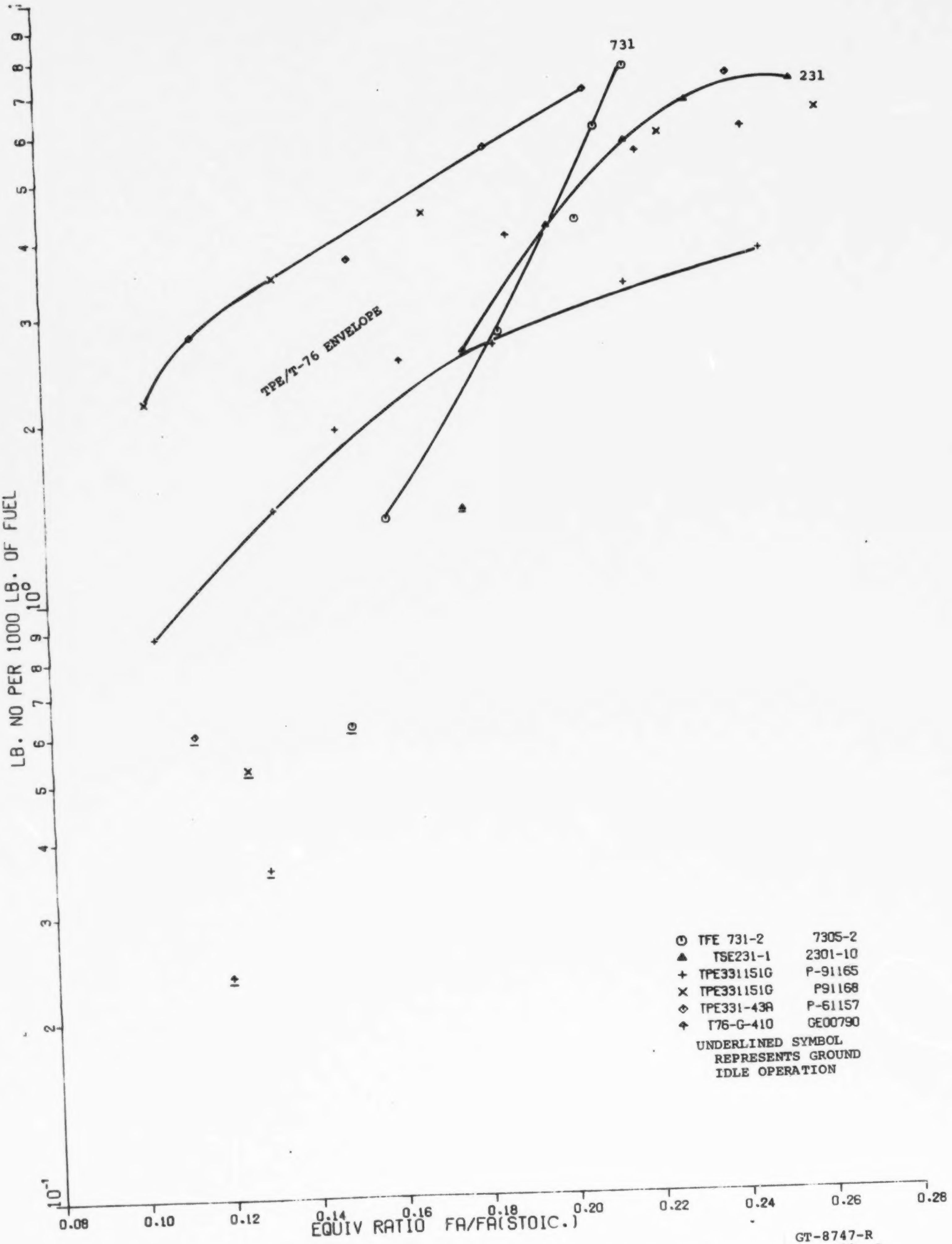

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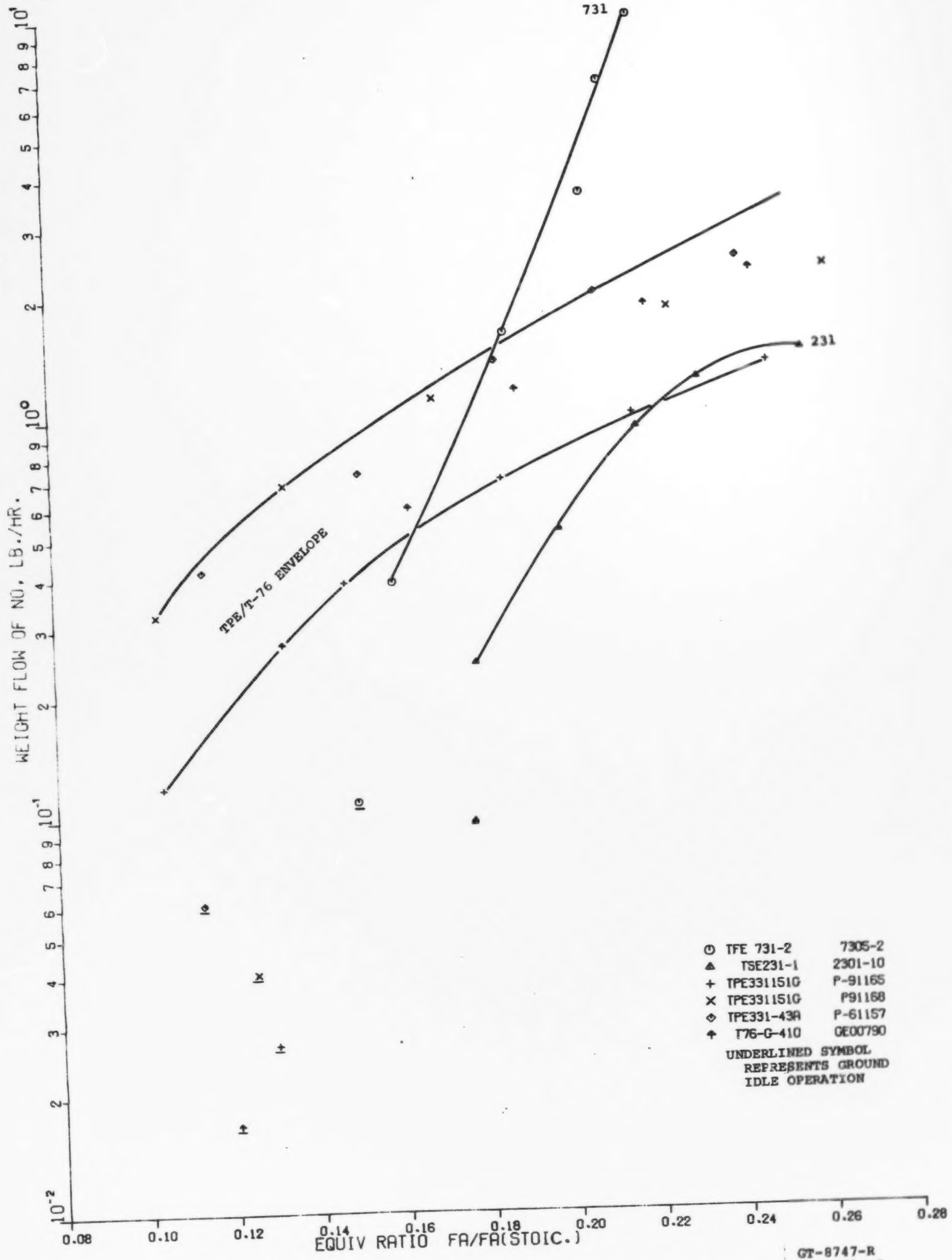

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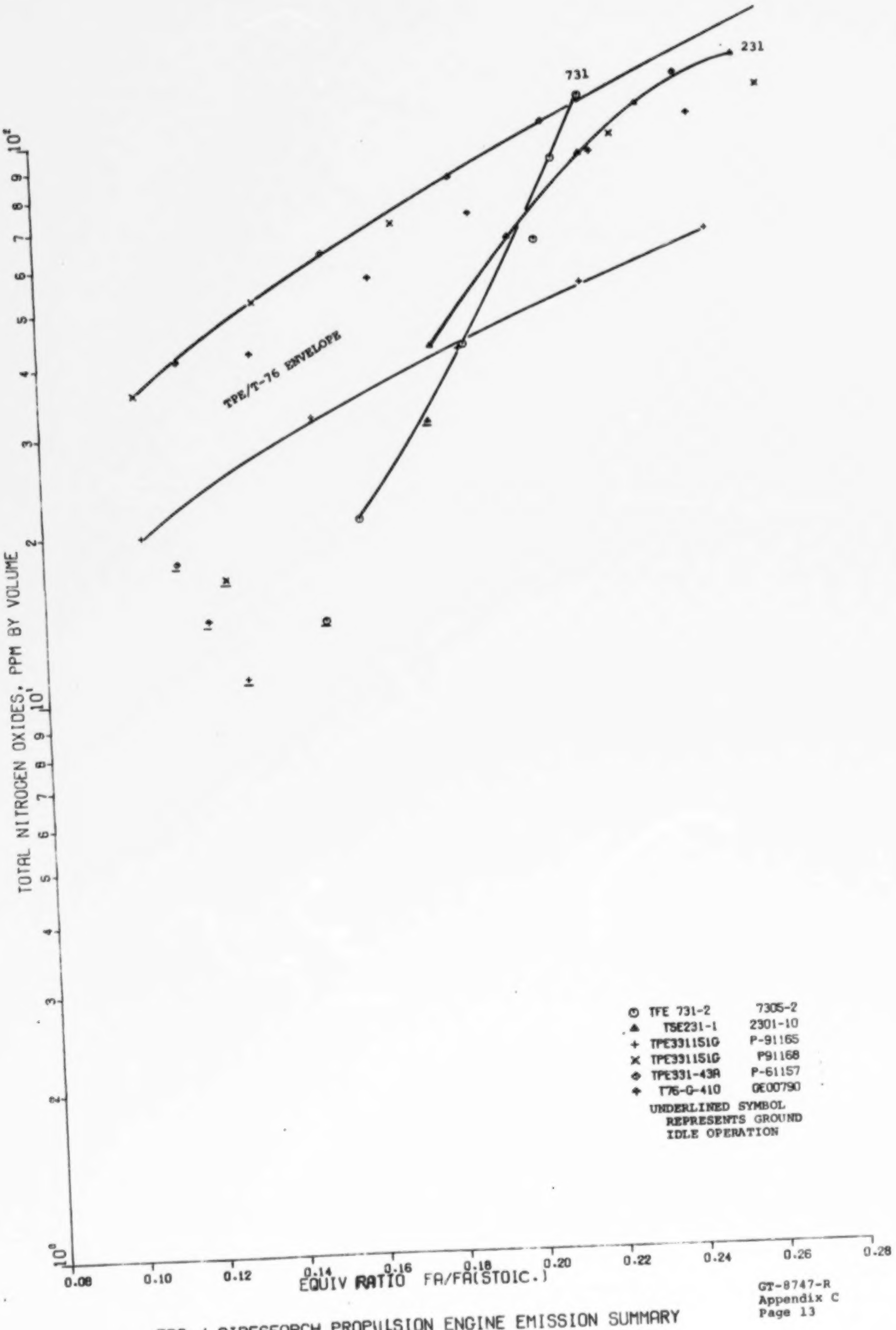

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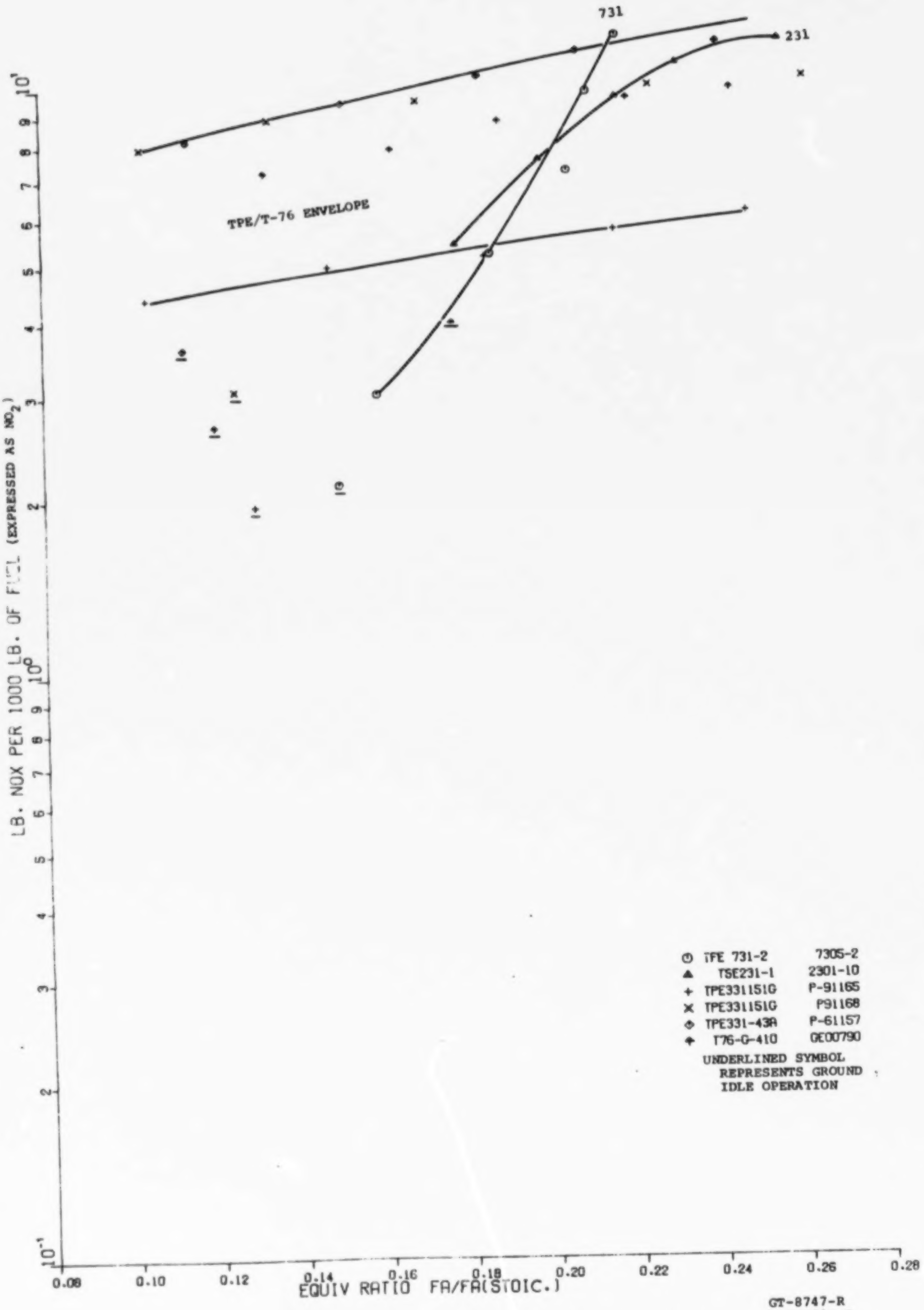

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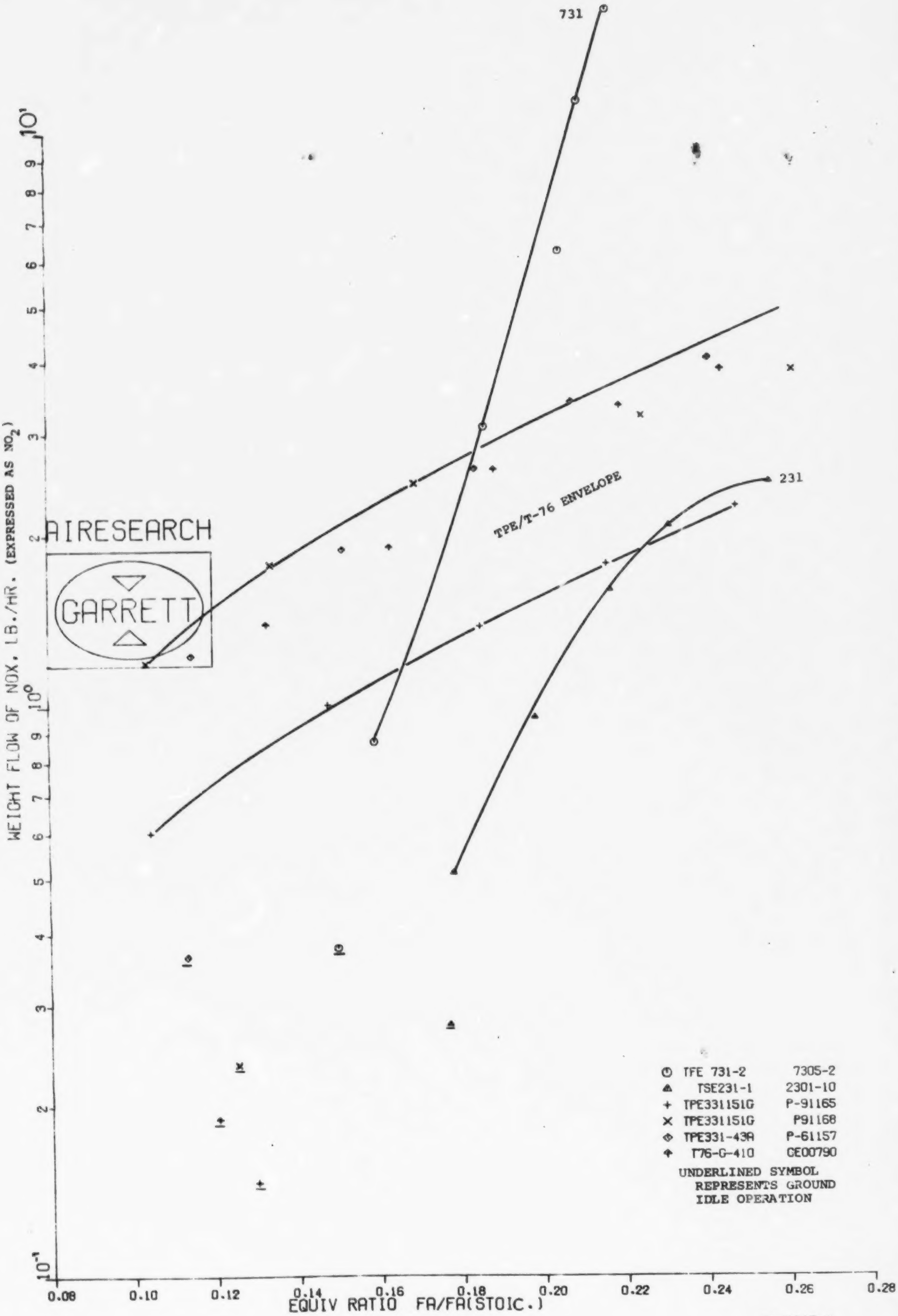

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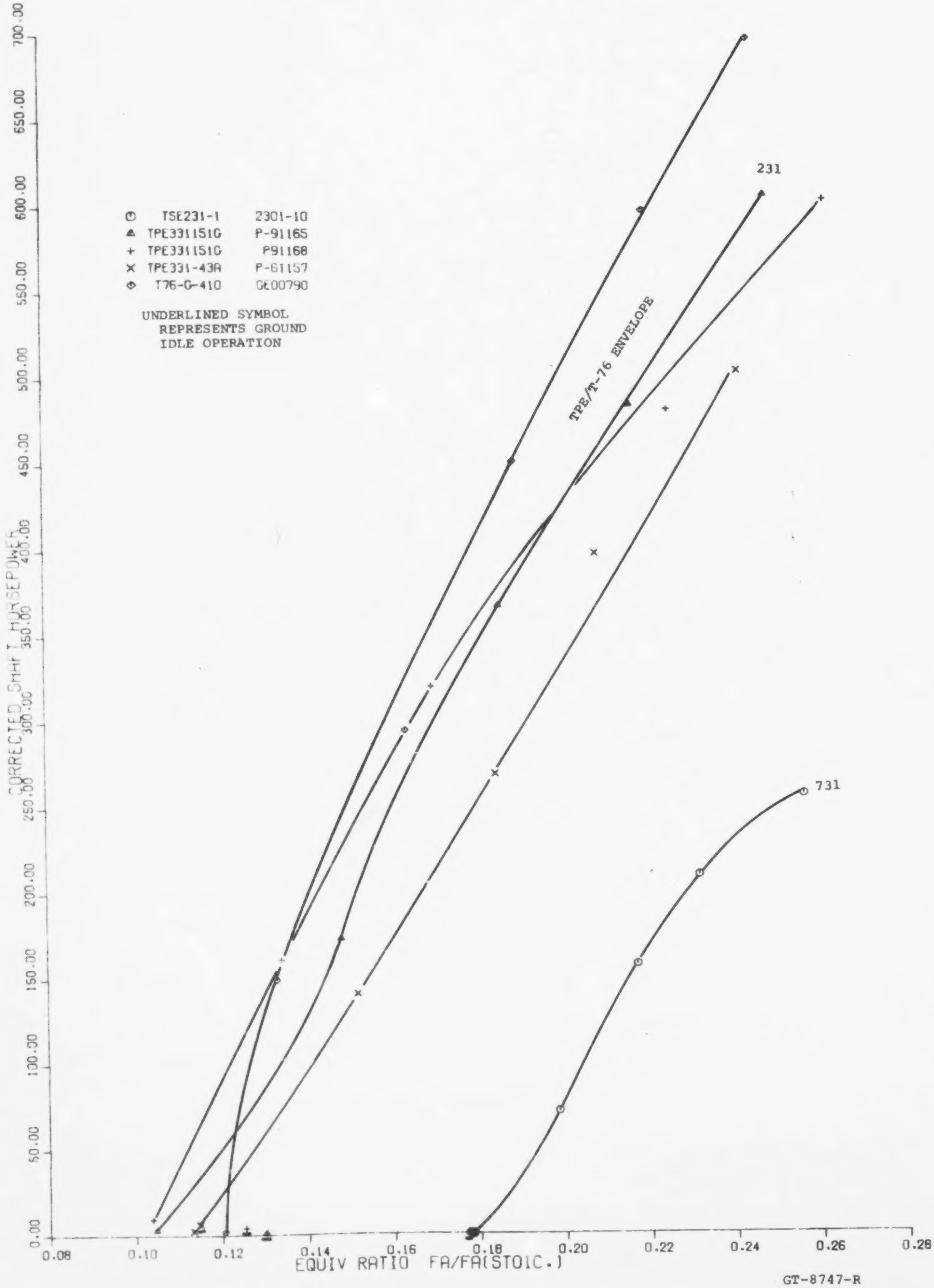
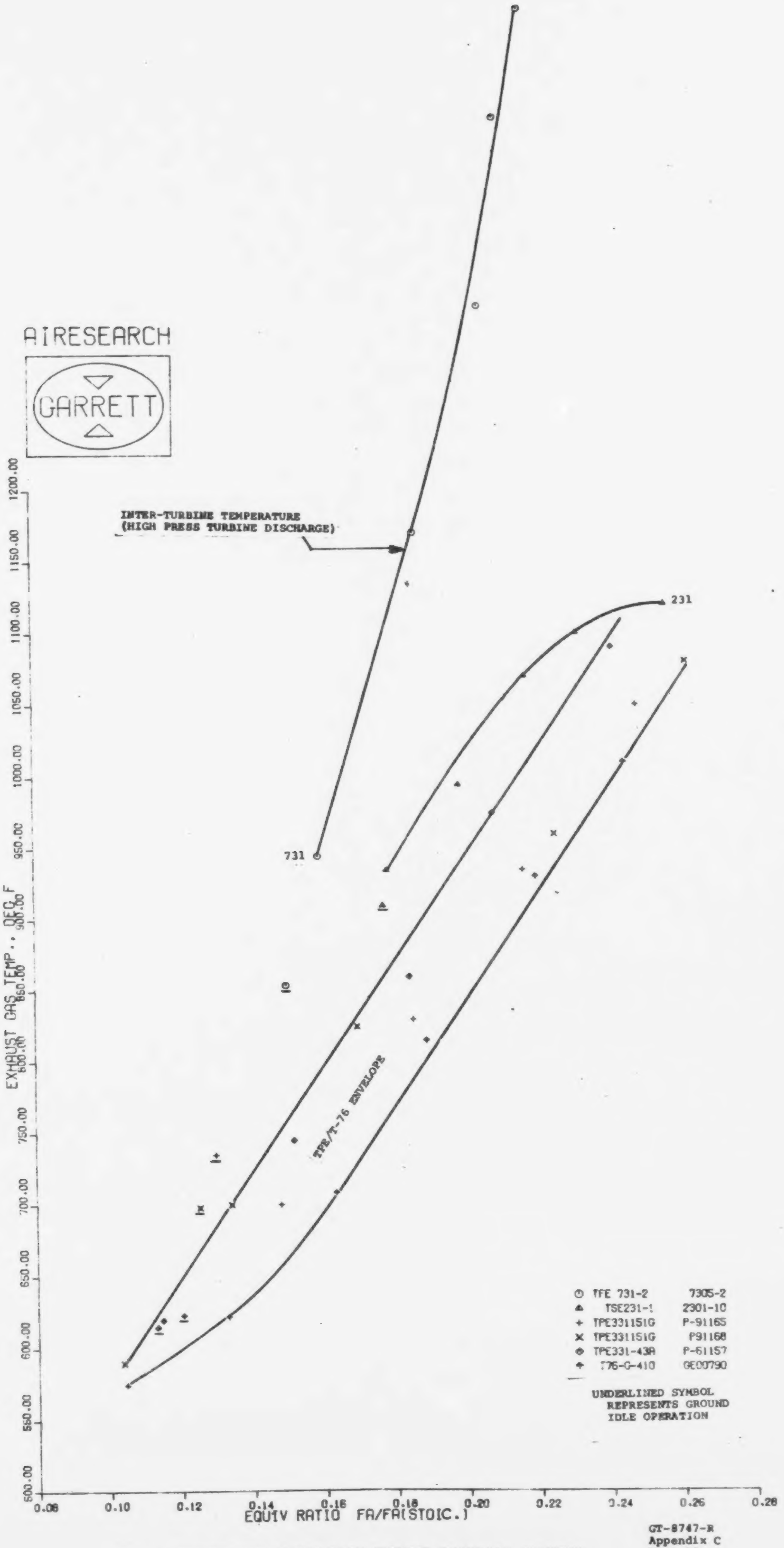


EPA / AIRESEARCH PROPULSION ENGINE EMISSION SUMMARY

AIRESEARCH

GARRETT



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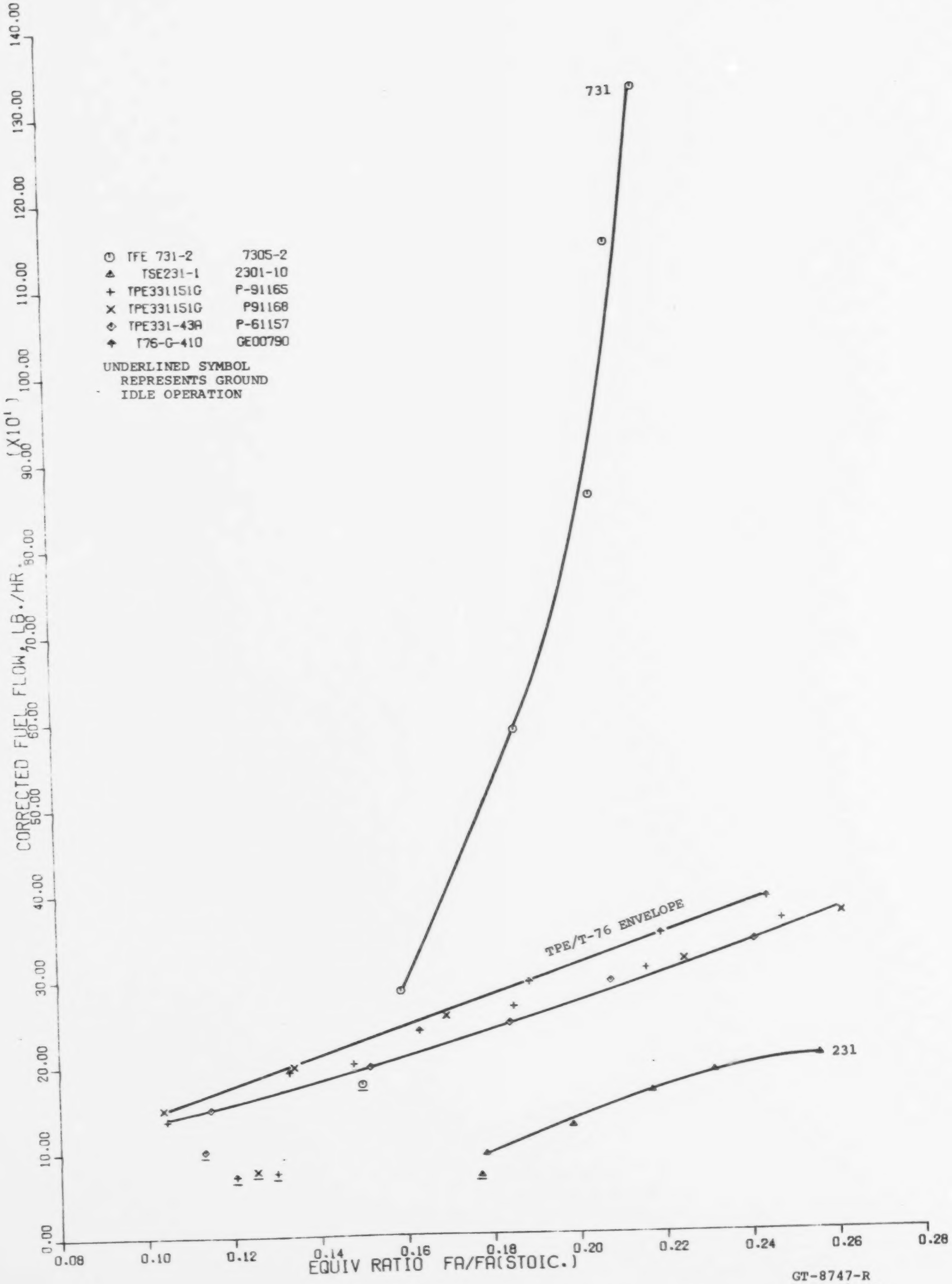

EPA / AIRESEARCH PROPULSION ENGINE EMISSION SUMMARY

AIRESEARCH MANUFACTURING COMPANY OF ARIZONA
A DIVISION OF THE GARRETT CORPORATION

GROUP 2

SMALL AUXILIARY POWER UNITS

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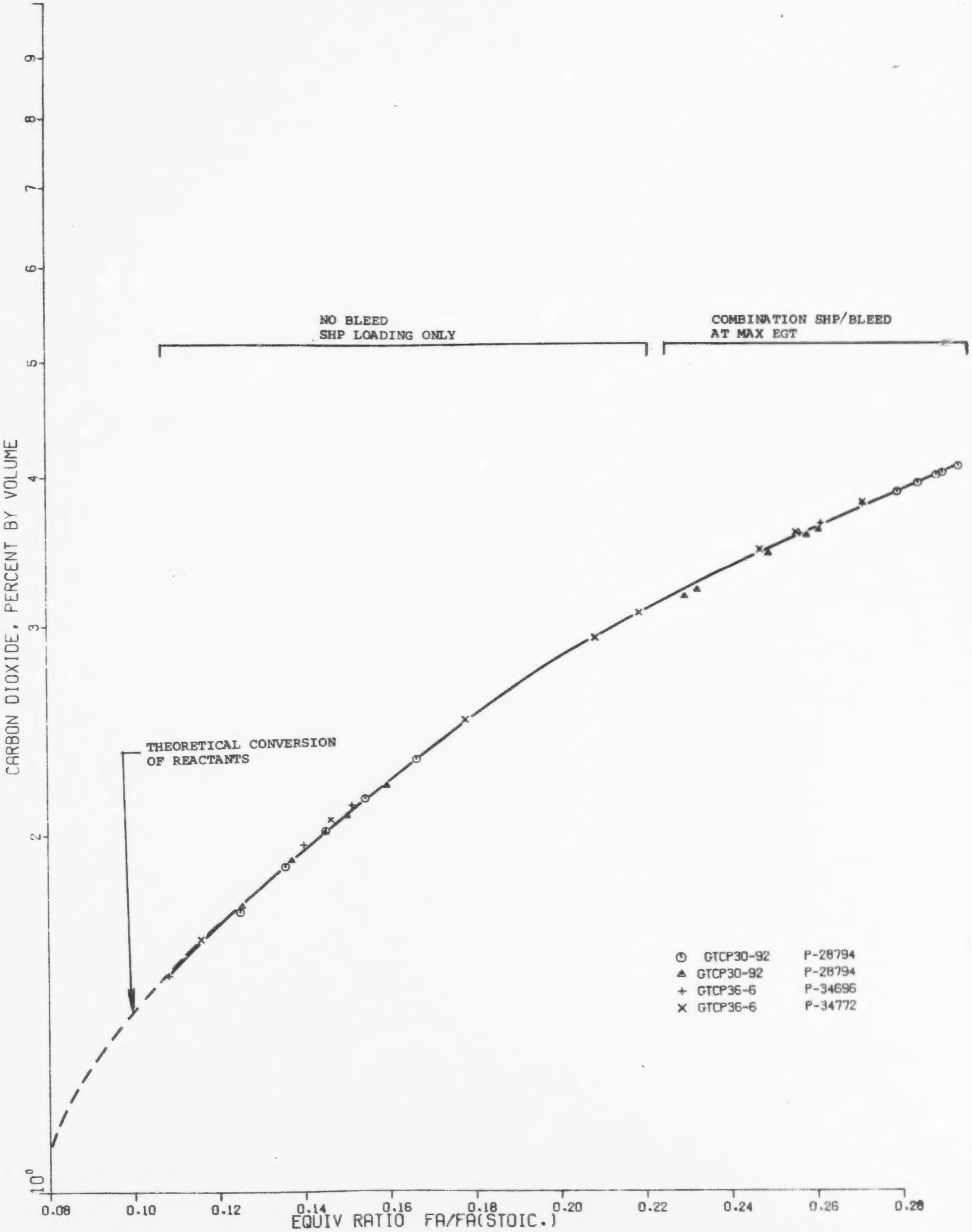
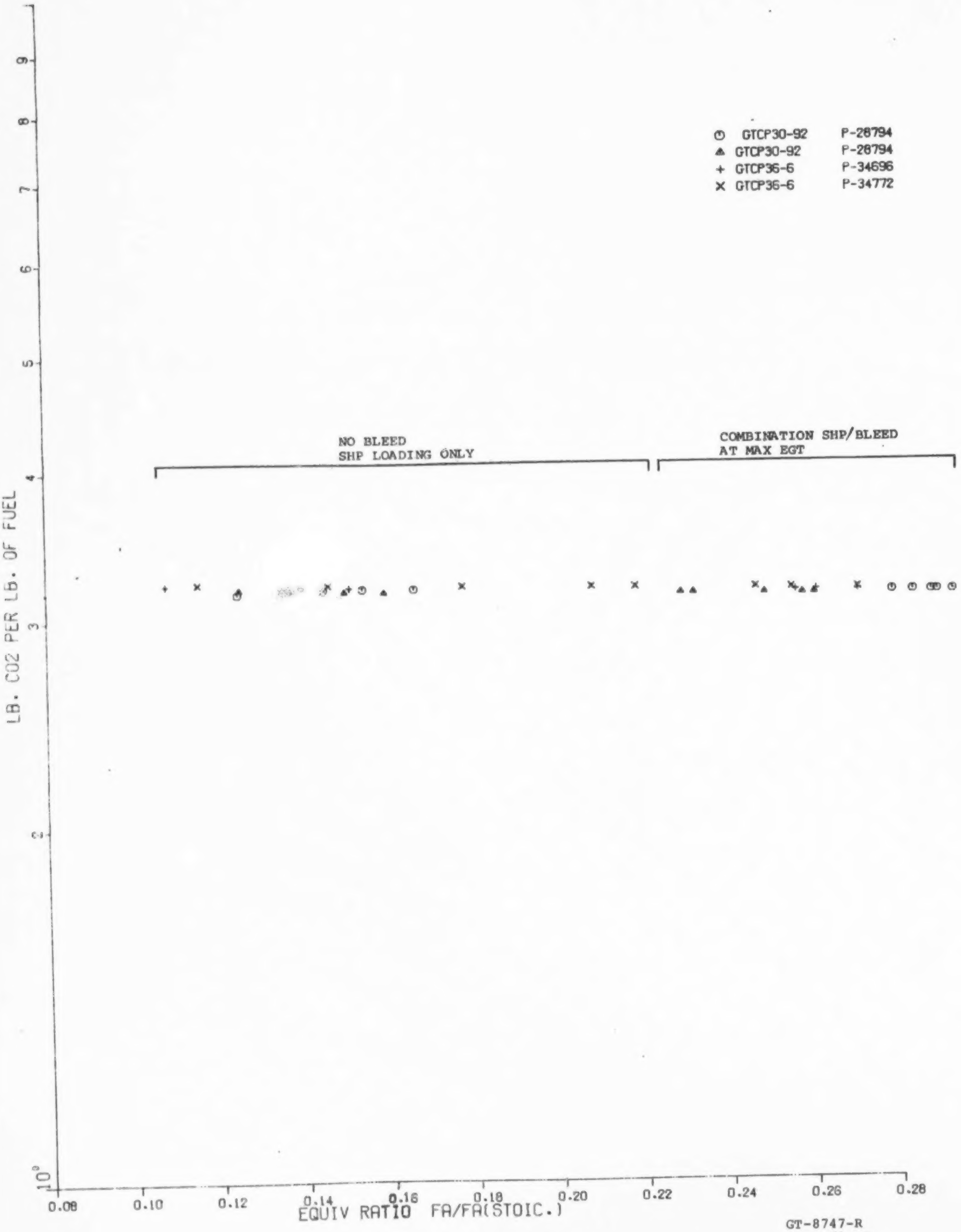


EPA / AIRESEARCH SMALL APU EXHAUST EMISSION SUMMARY



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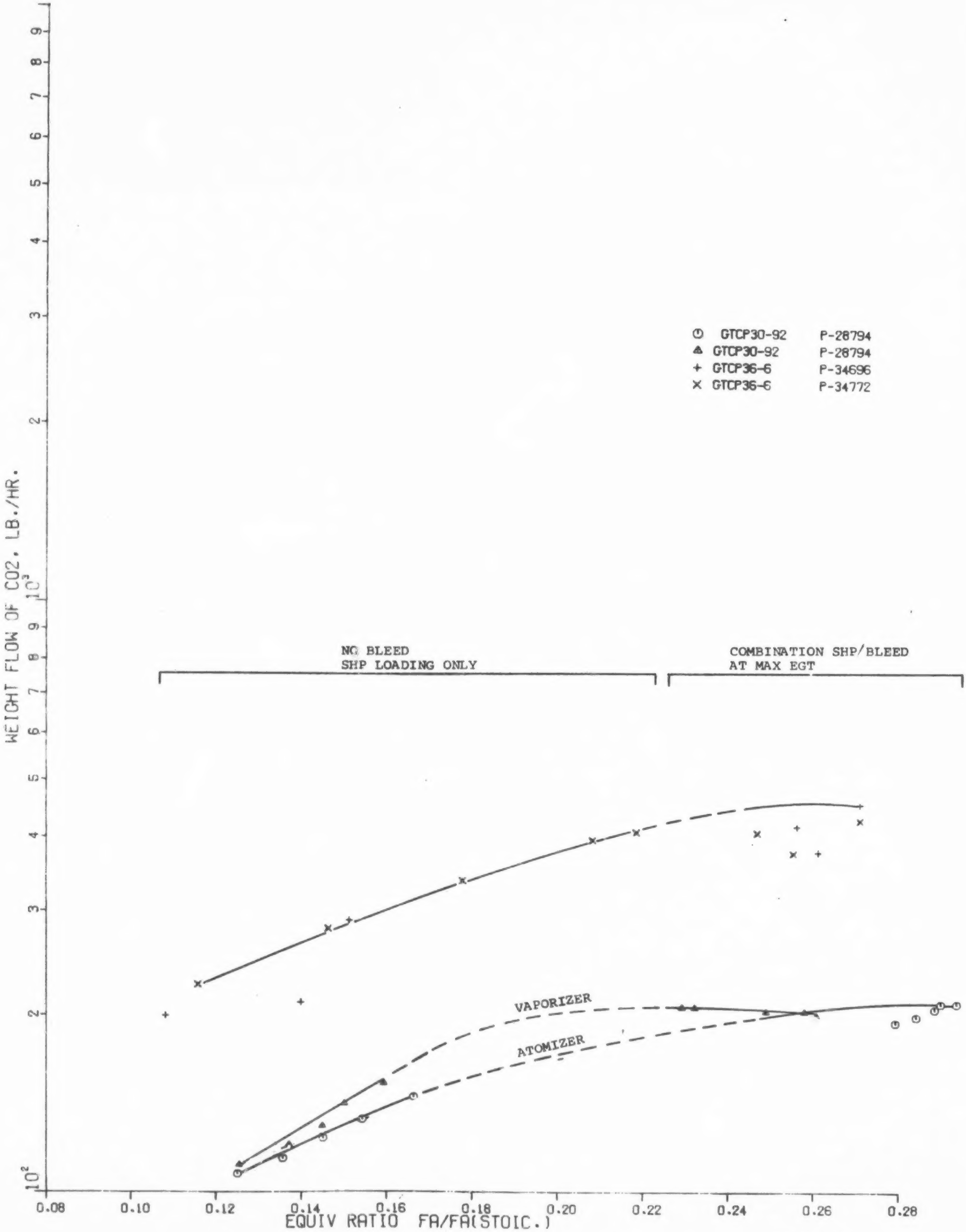

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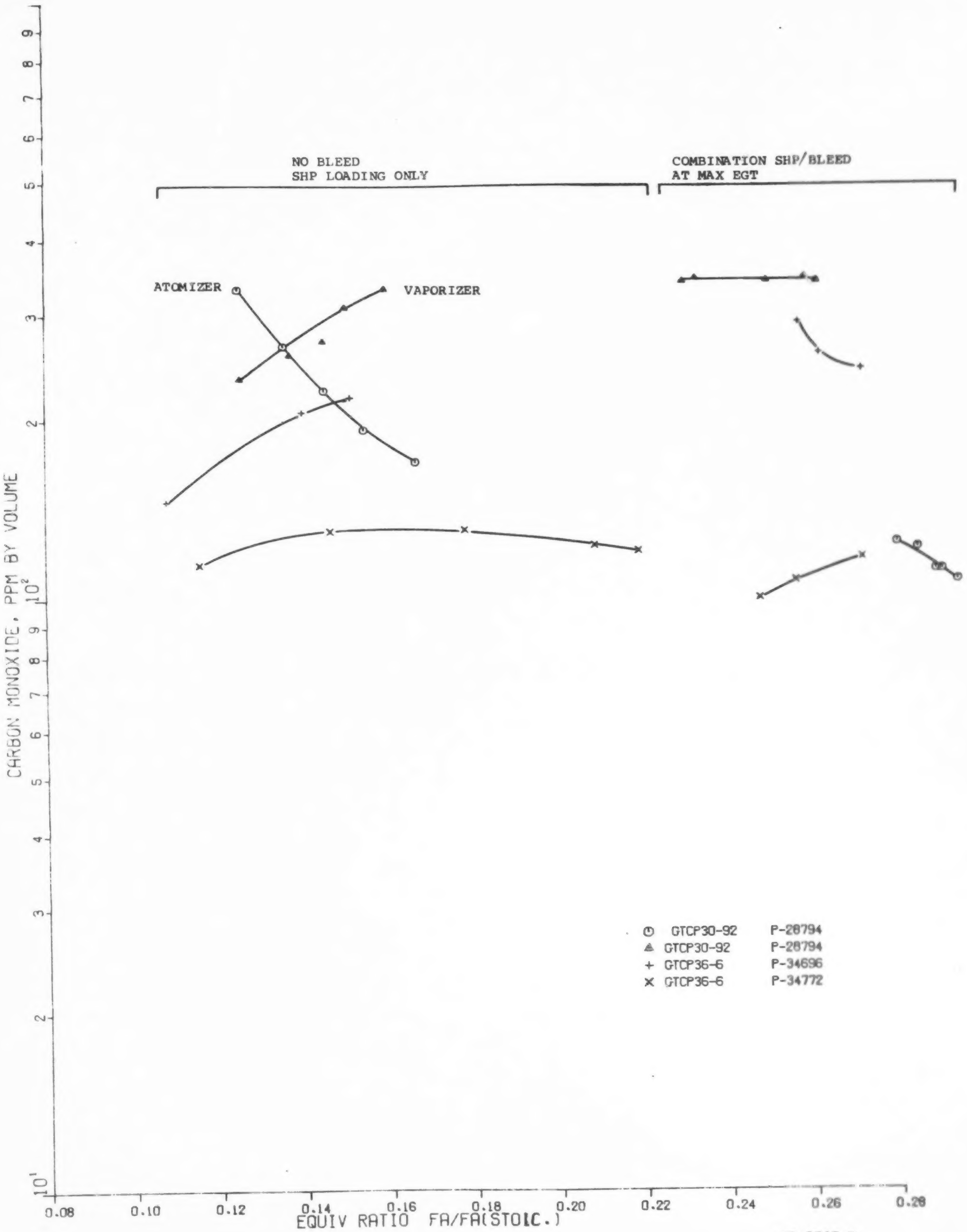

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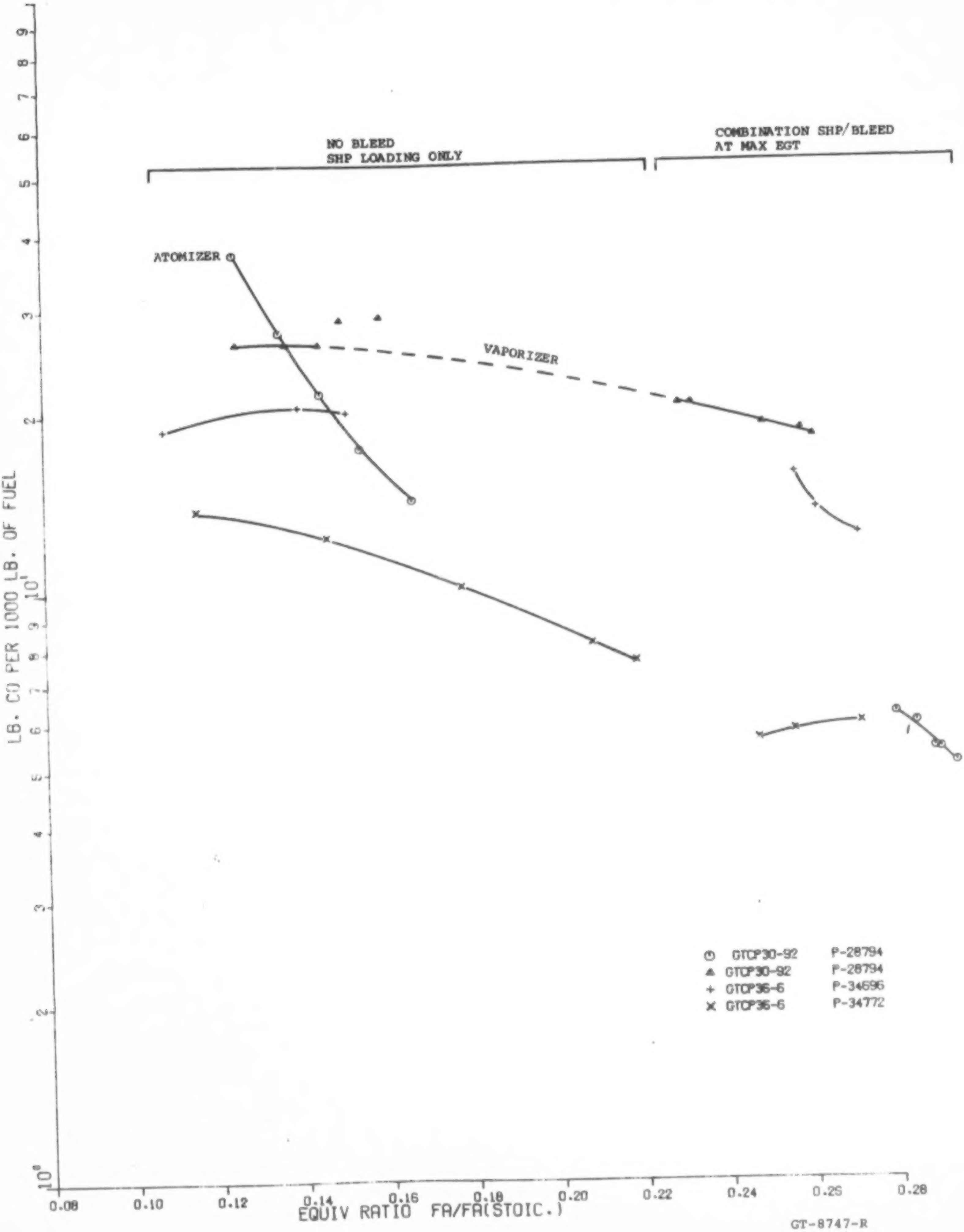

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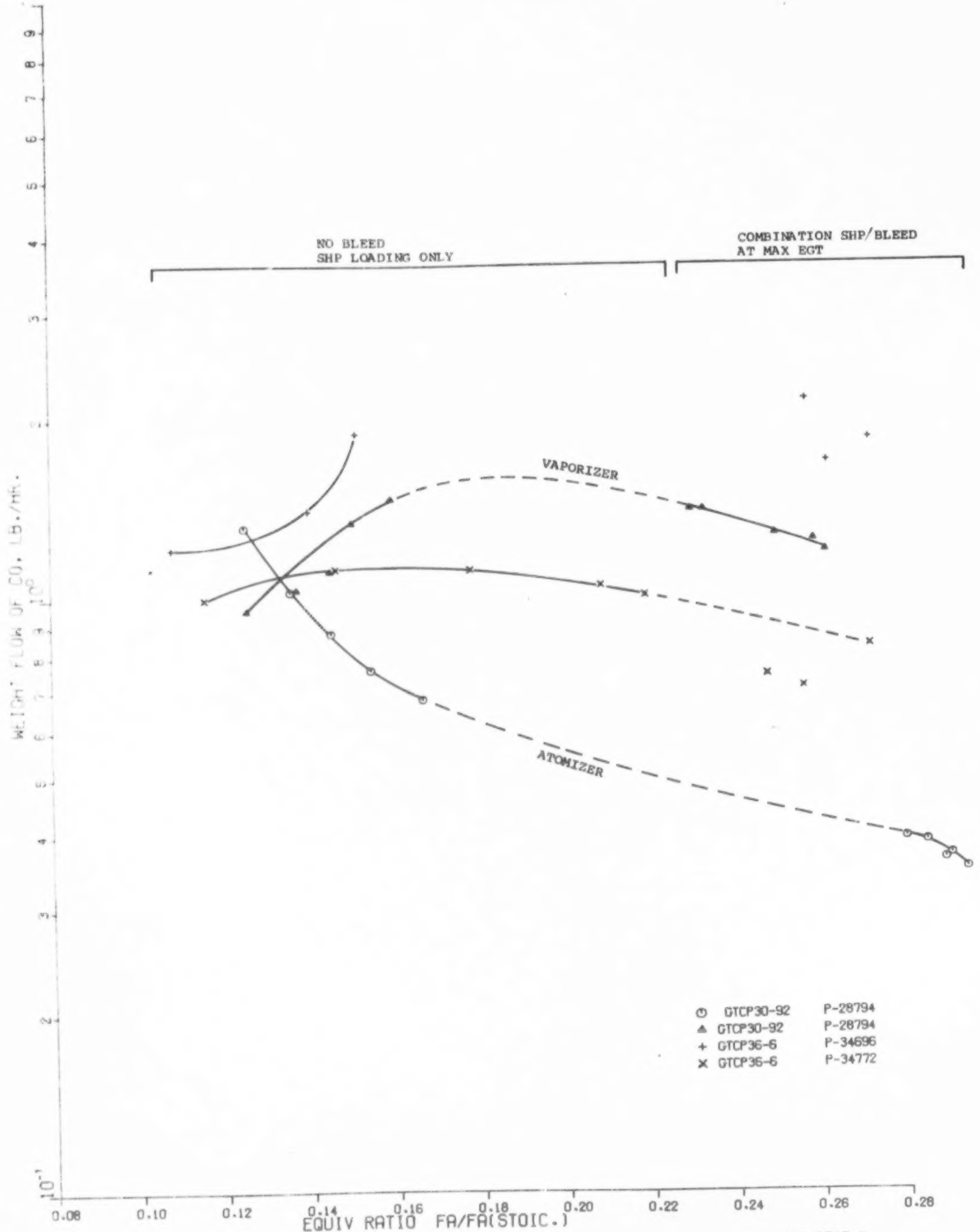

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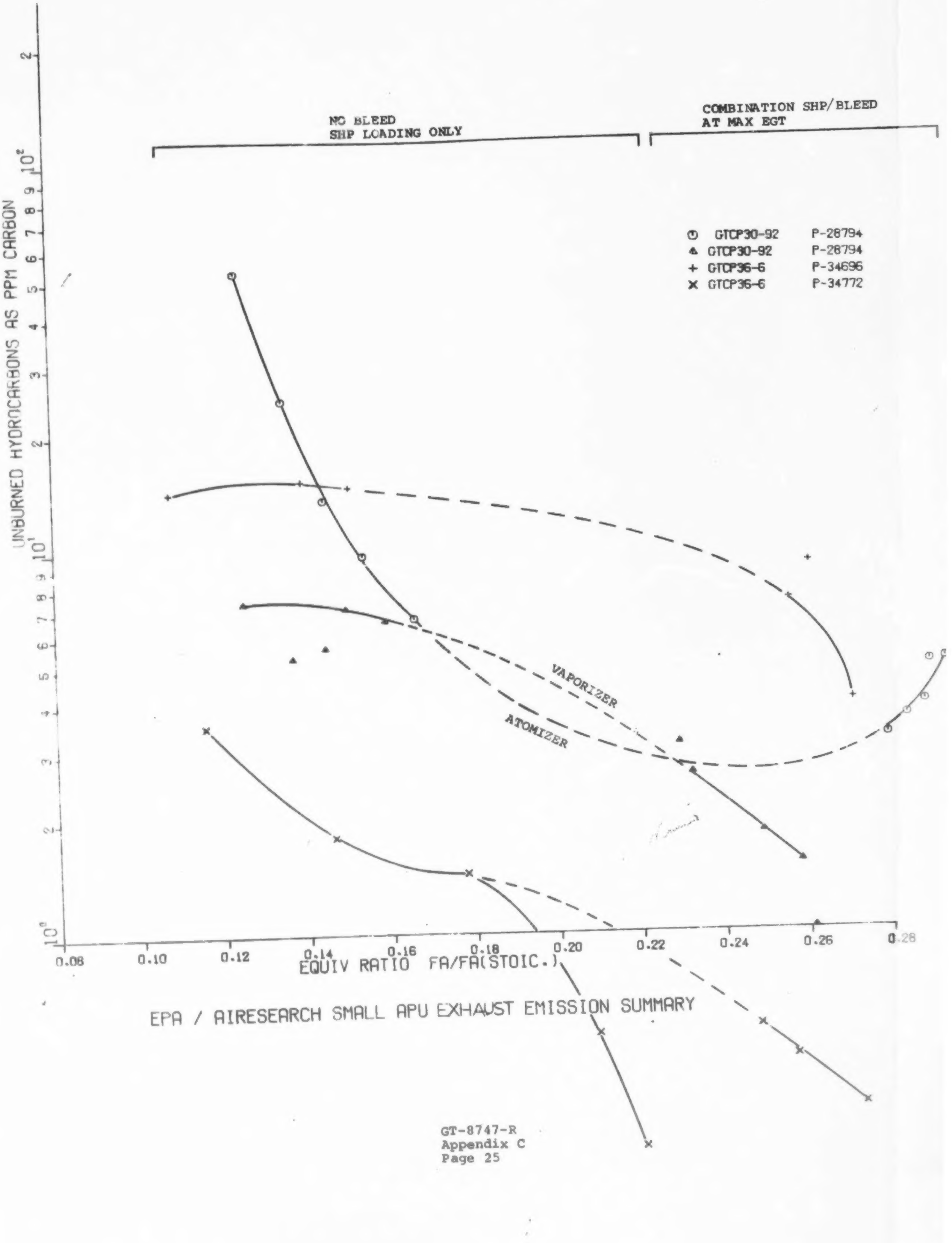

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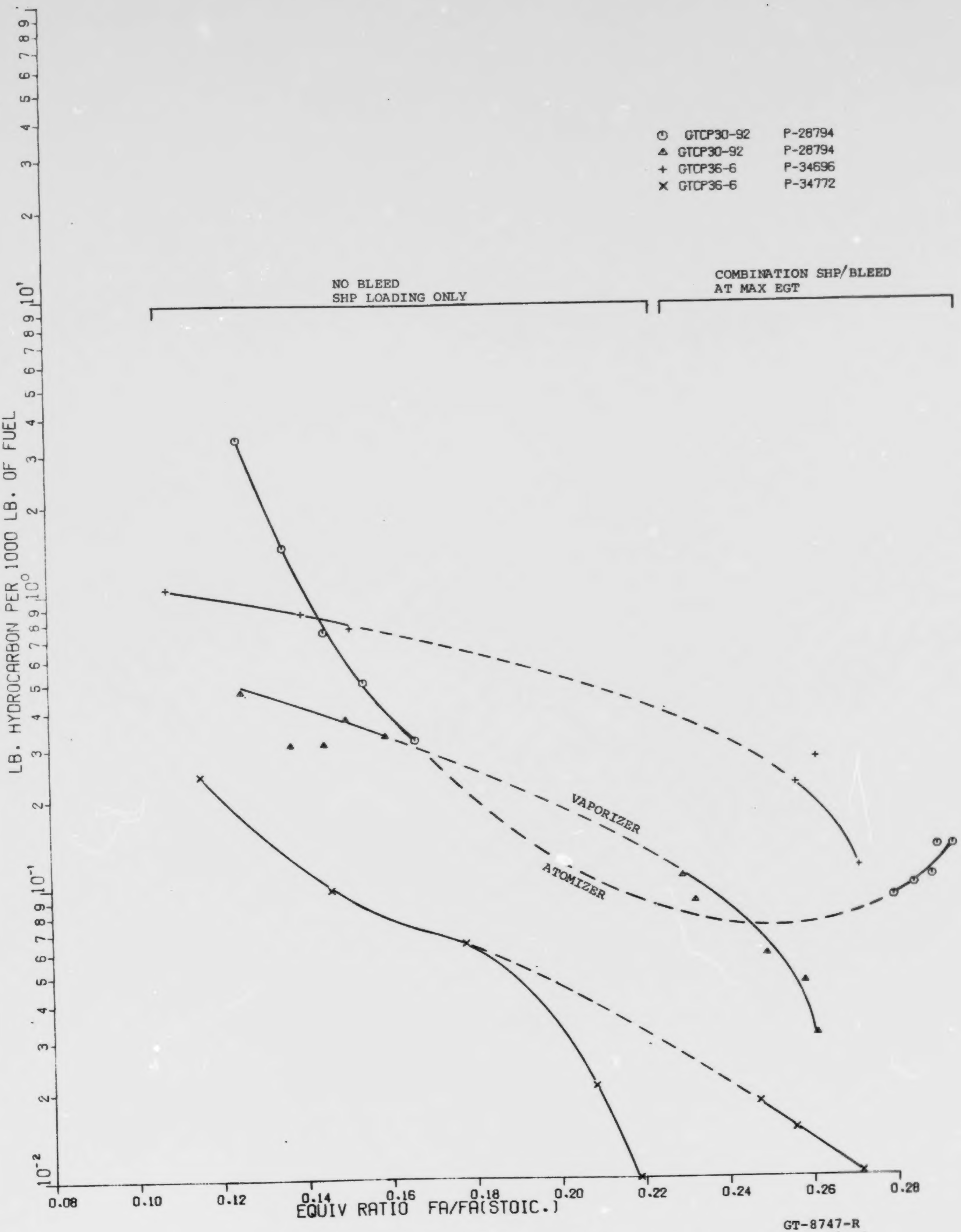

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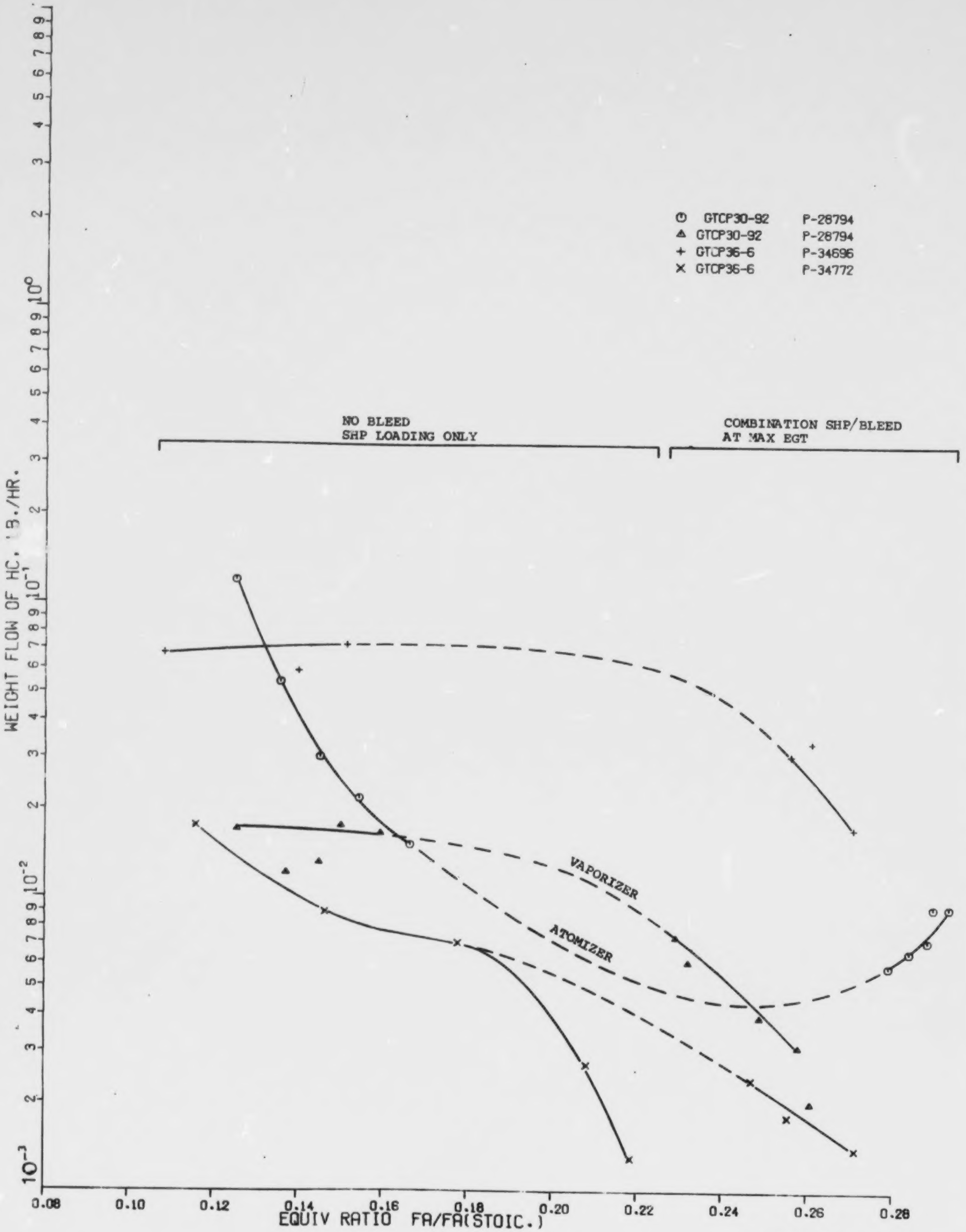

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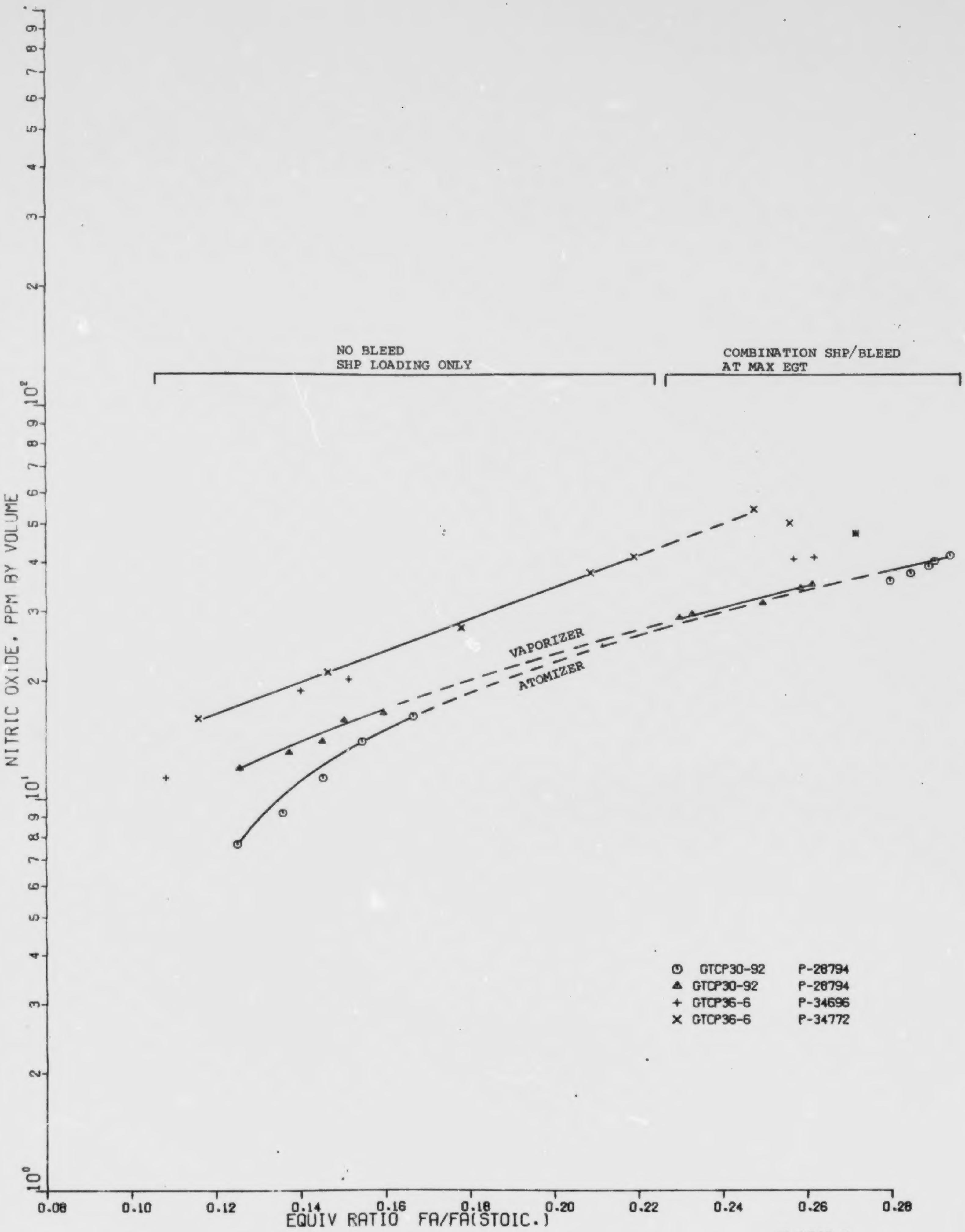

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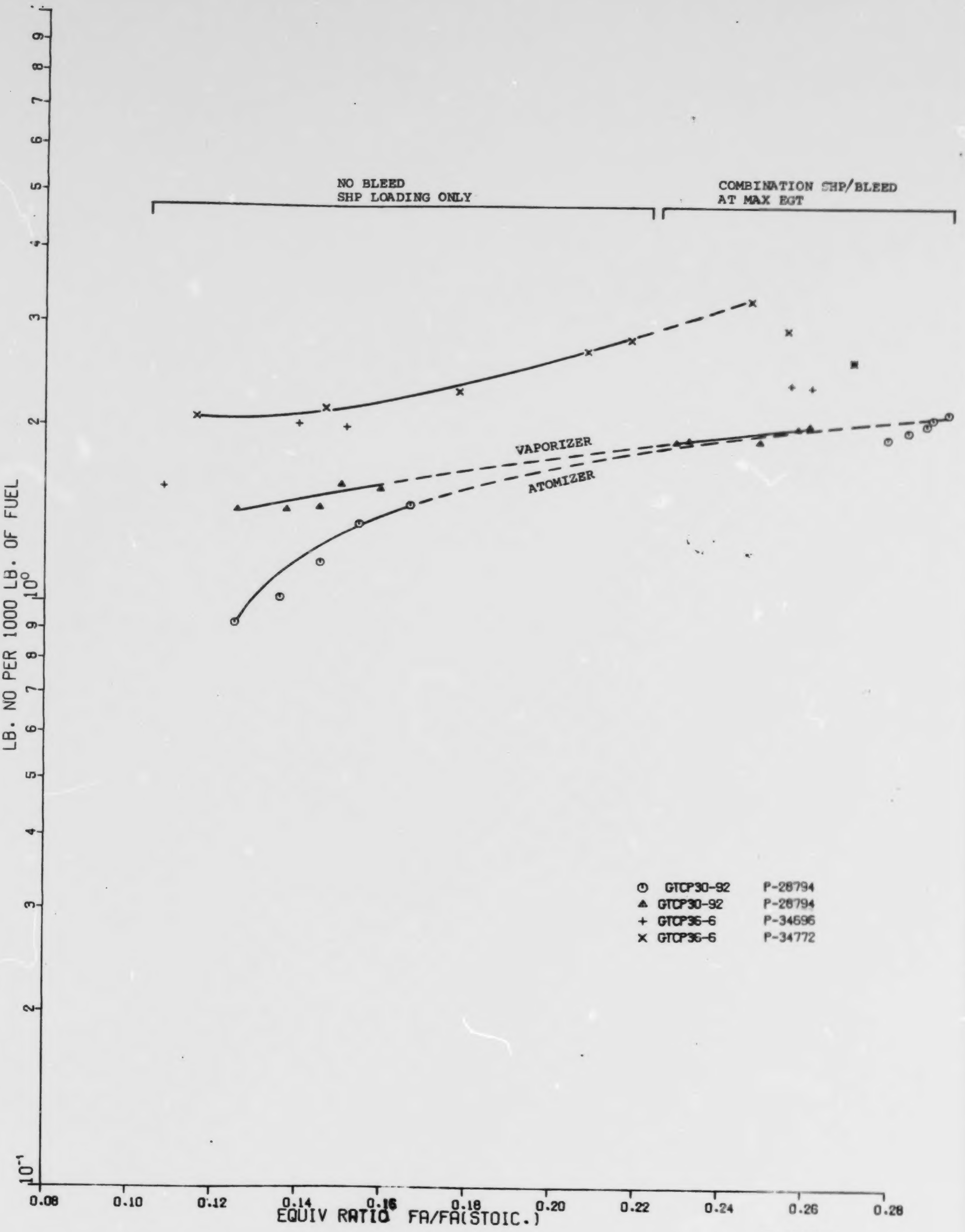

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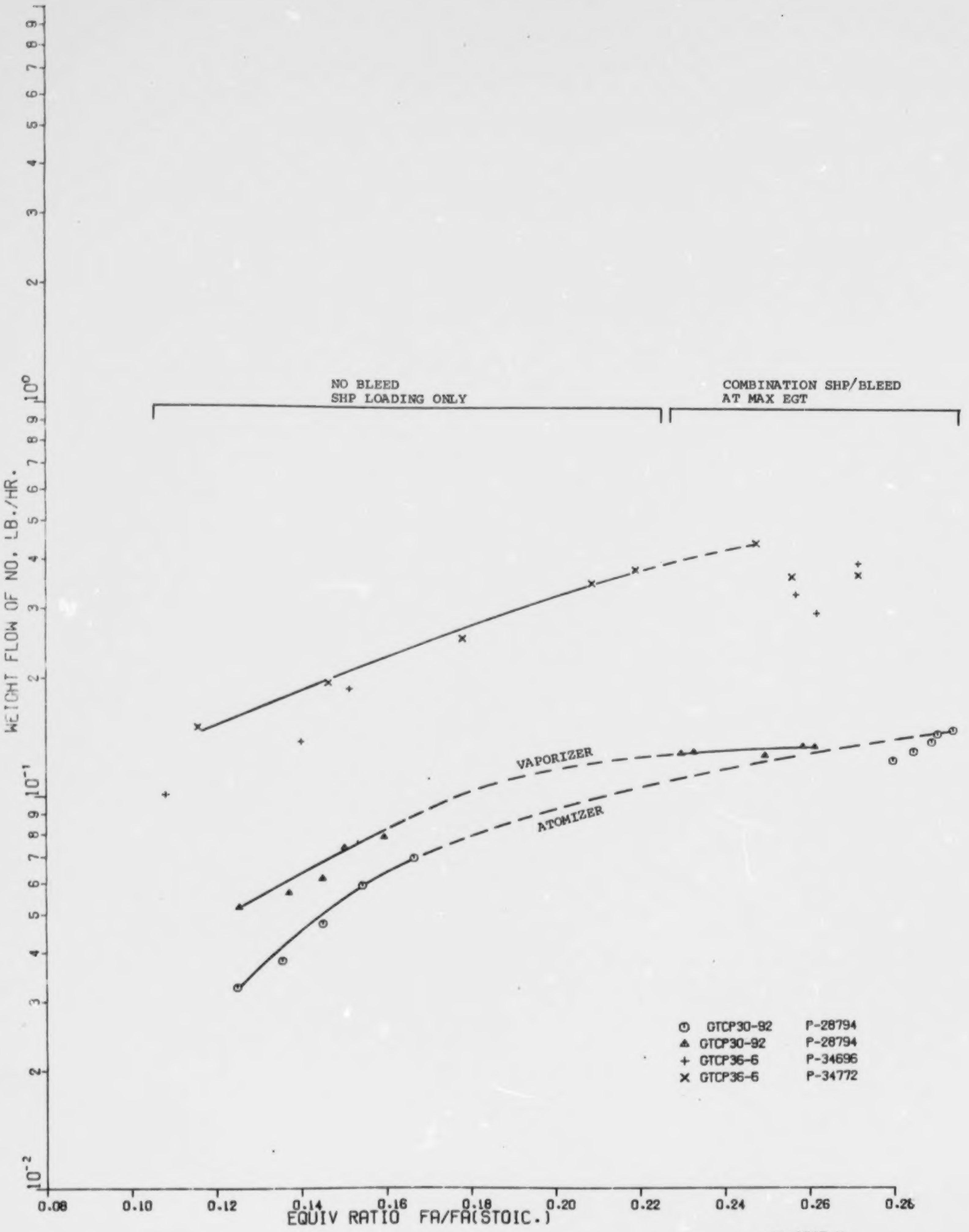

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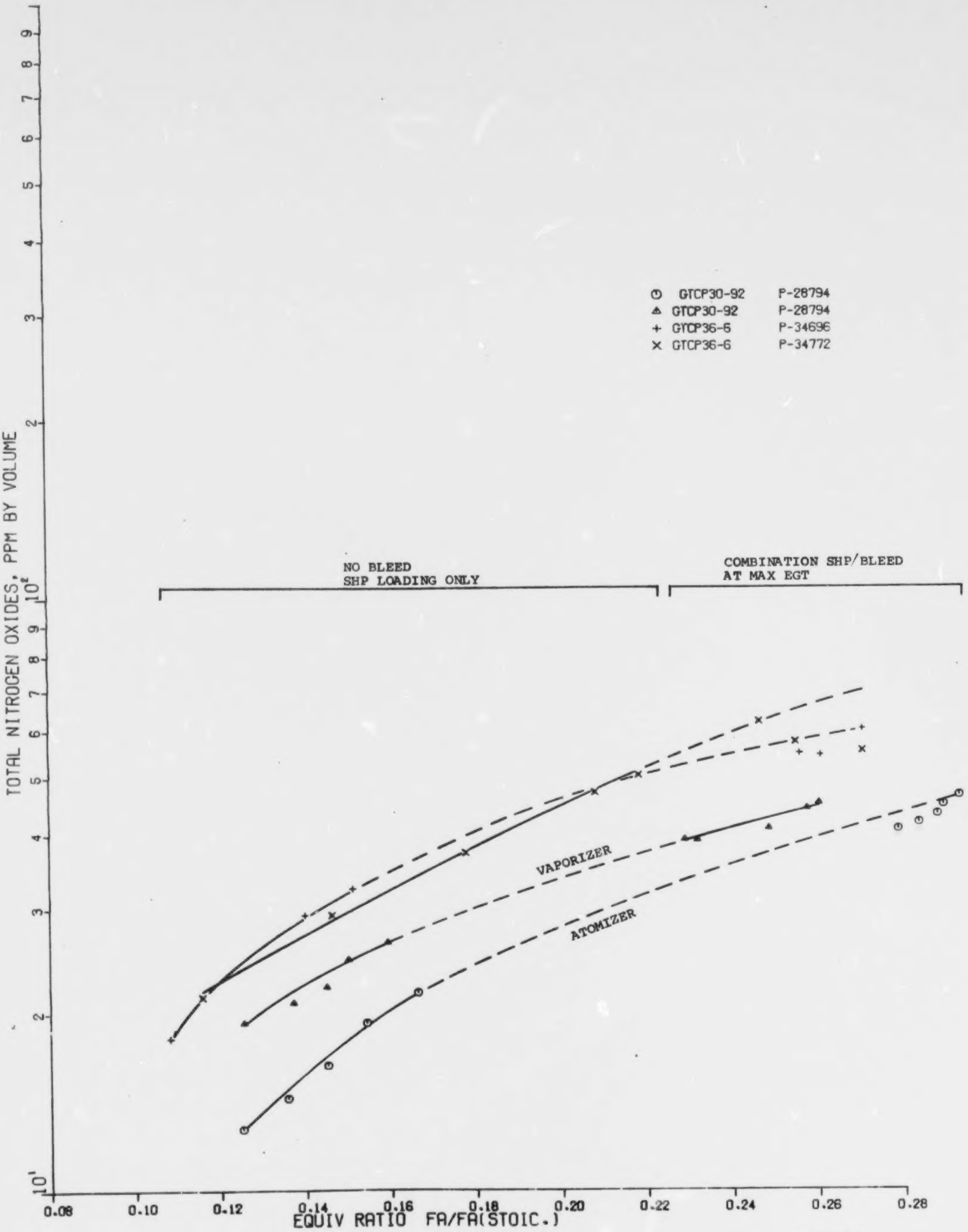

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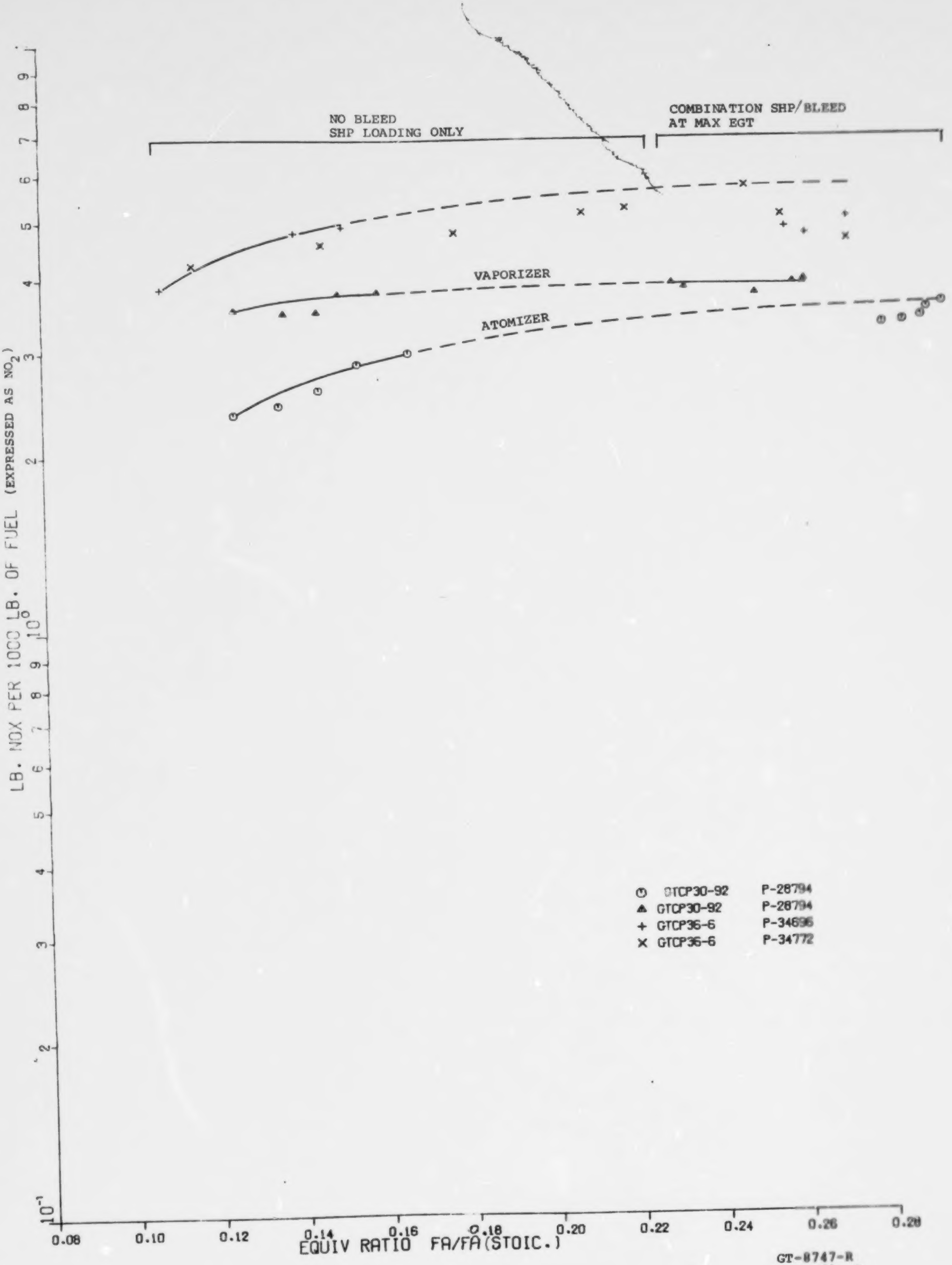

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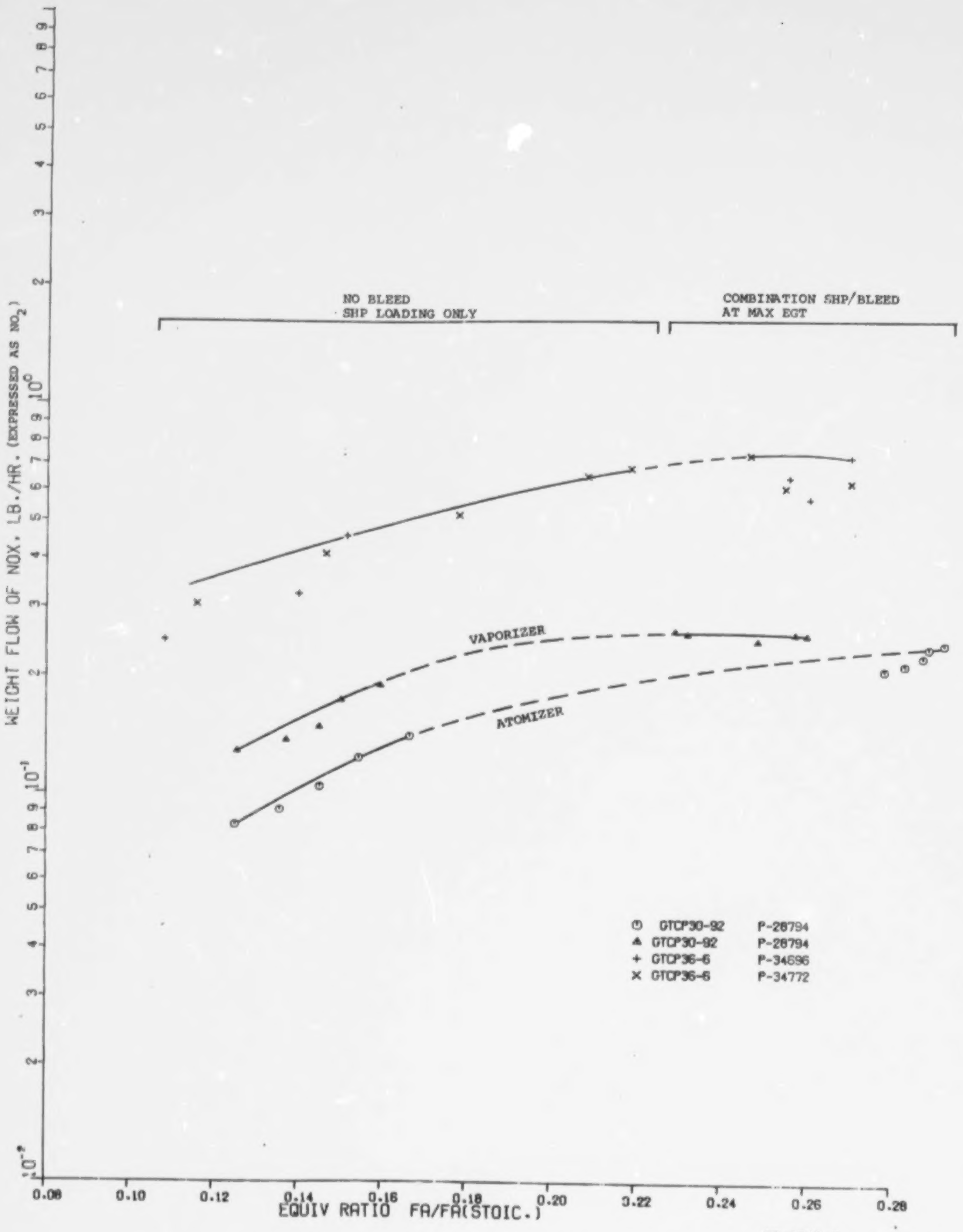

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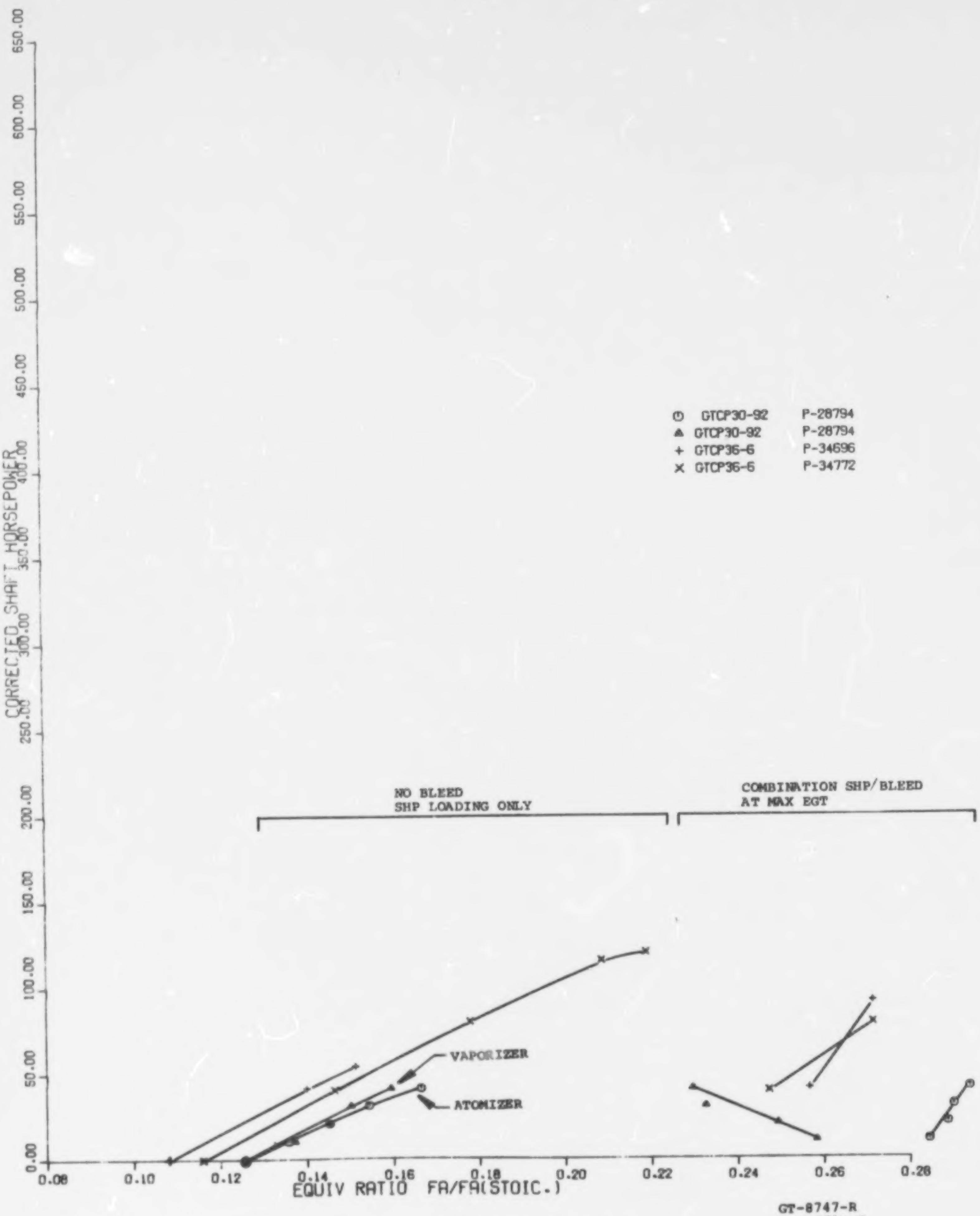

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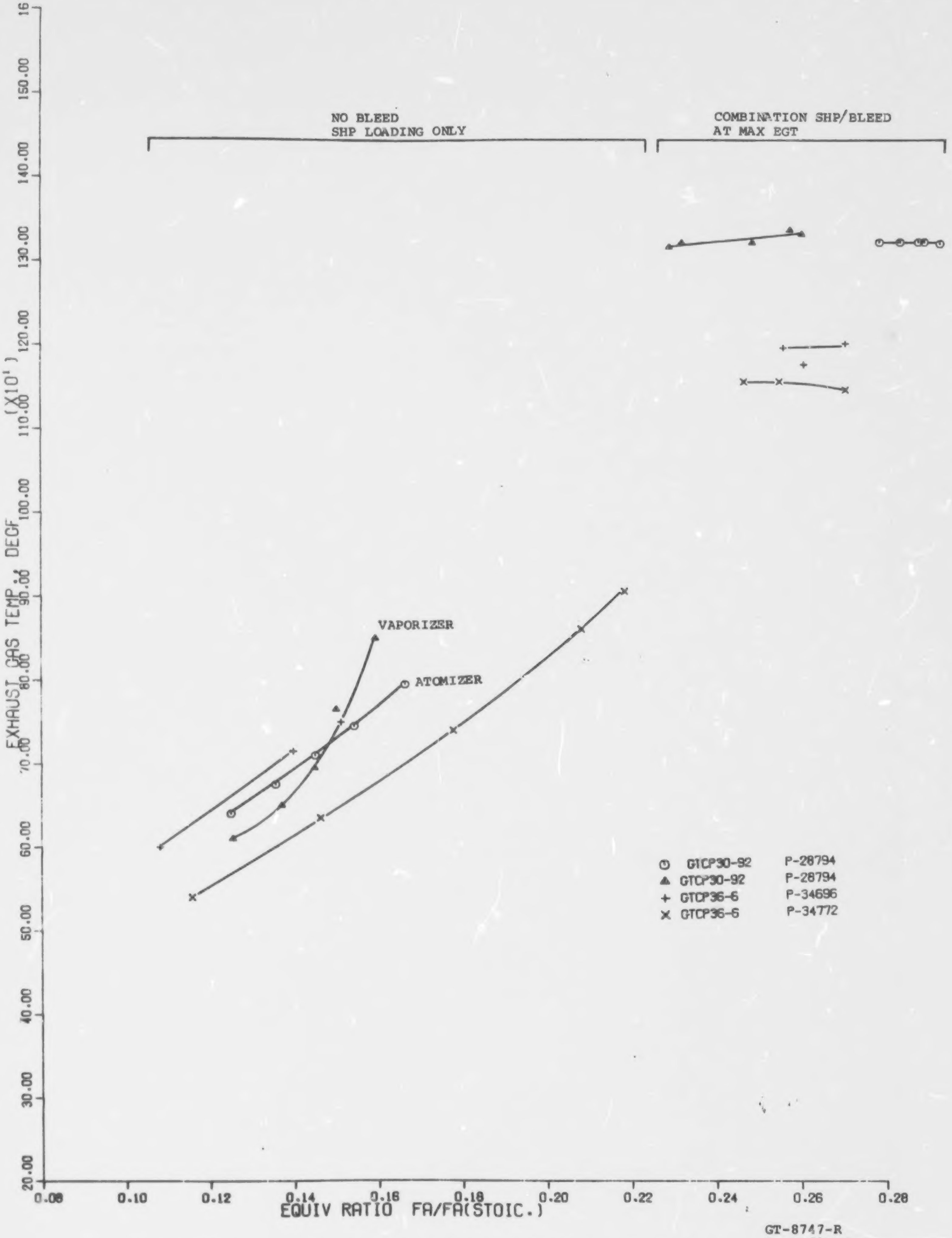

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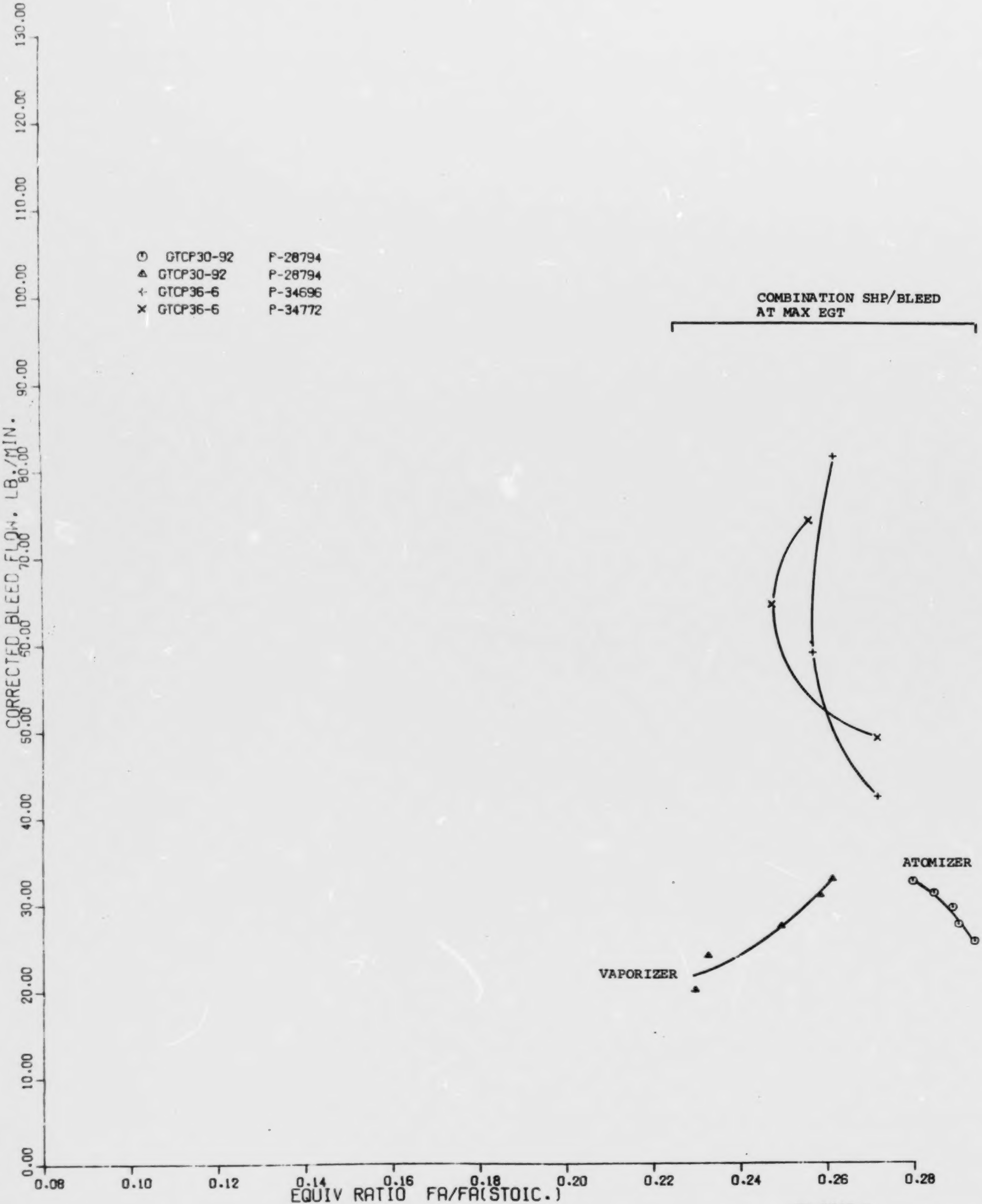

EPA / AIRESEARCH SMALL APU EXHAUST EMISSION SUMMARY

GROUP 3

MEDIUM-SIZE AUXILIARY POWER UNITS

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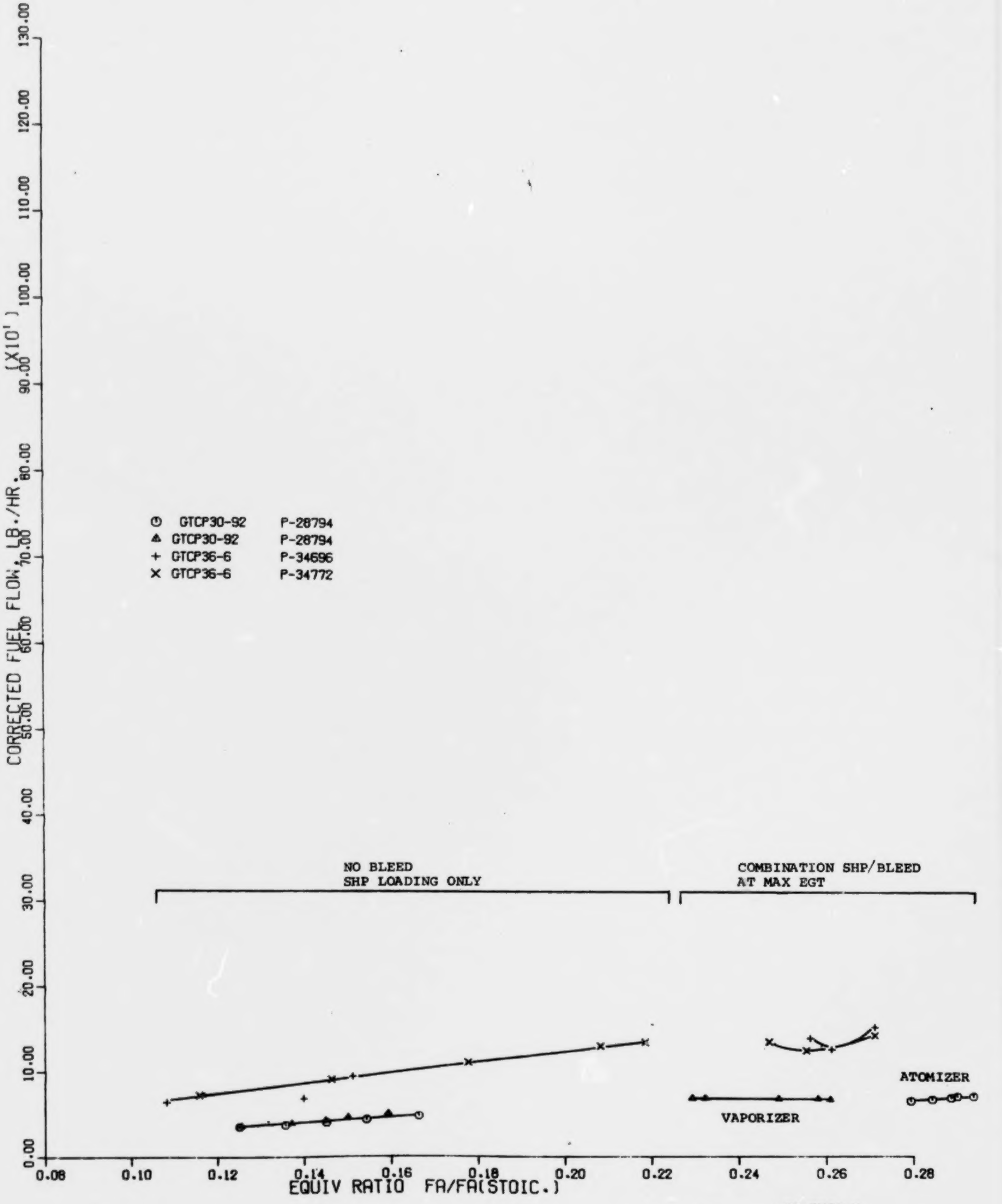

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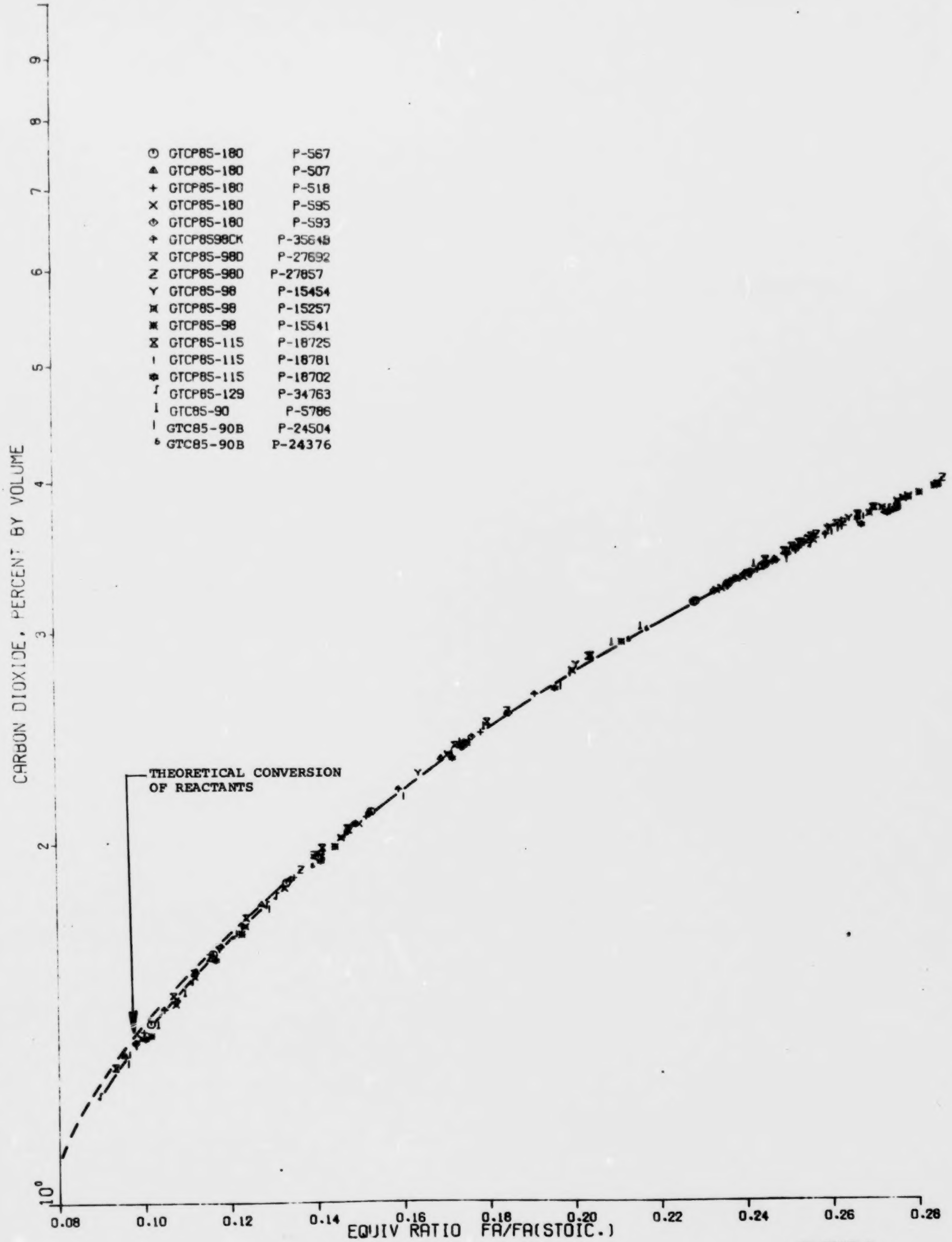

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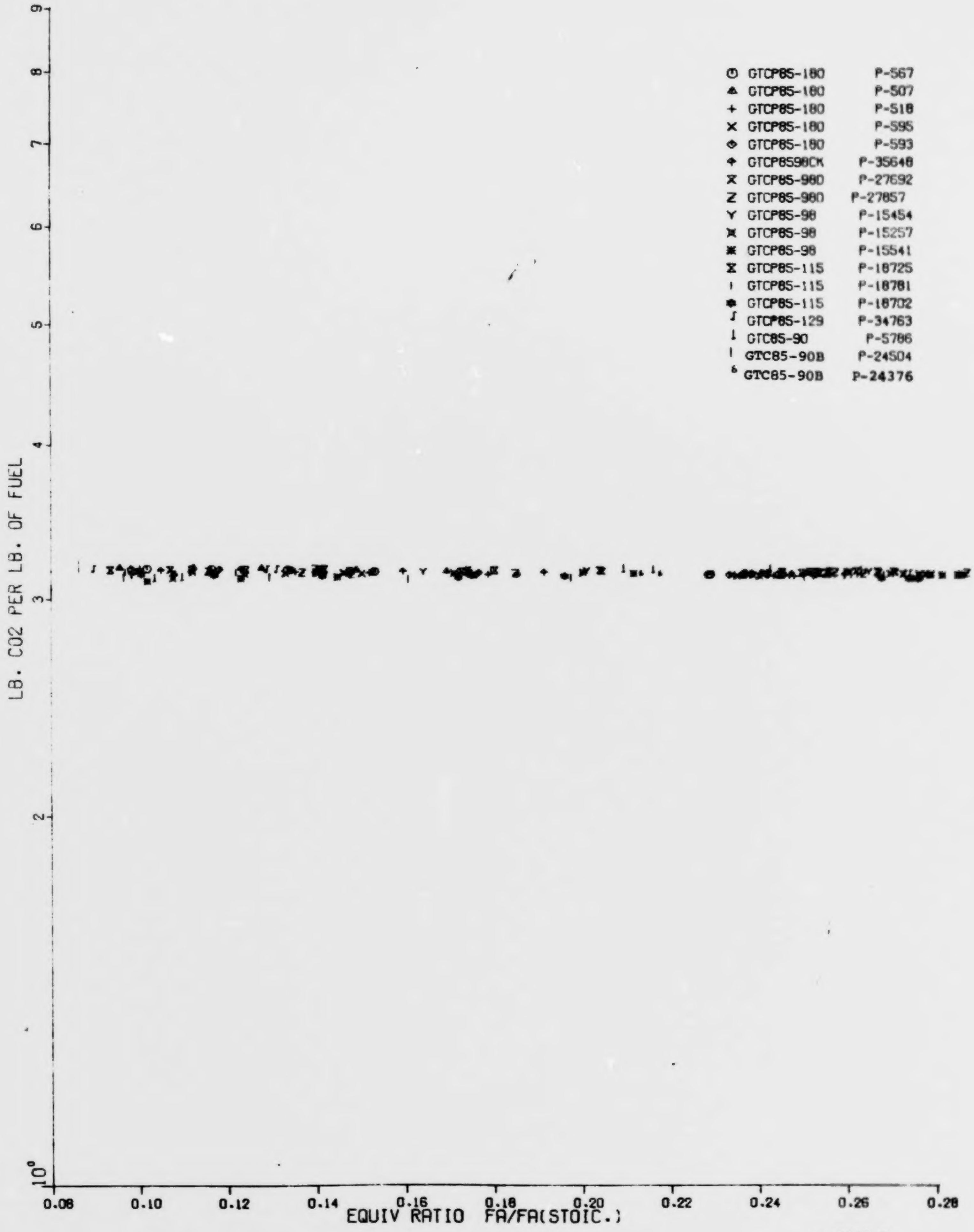

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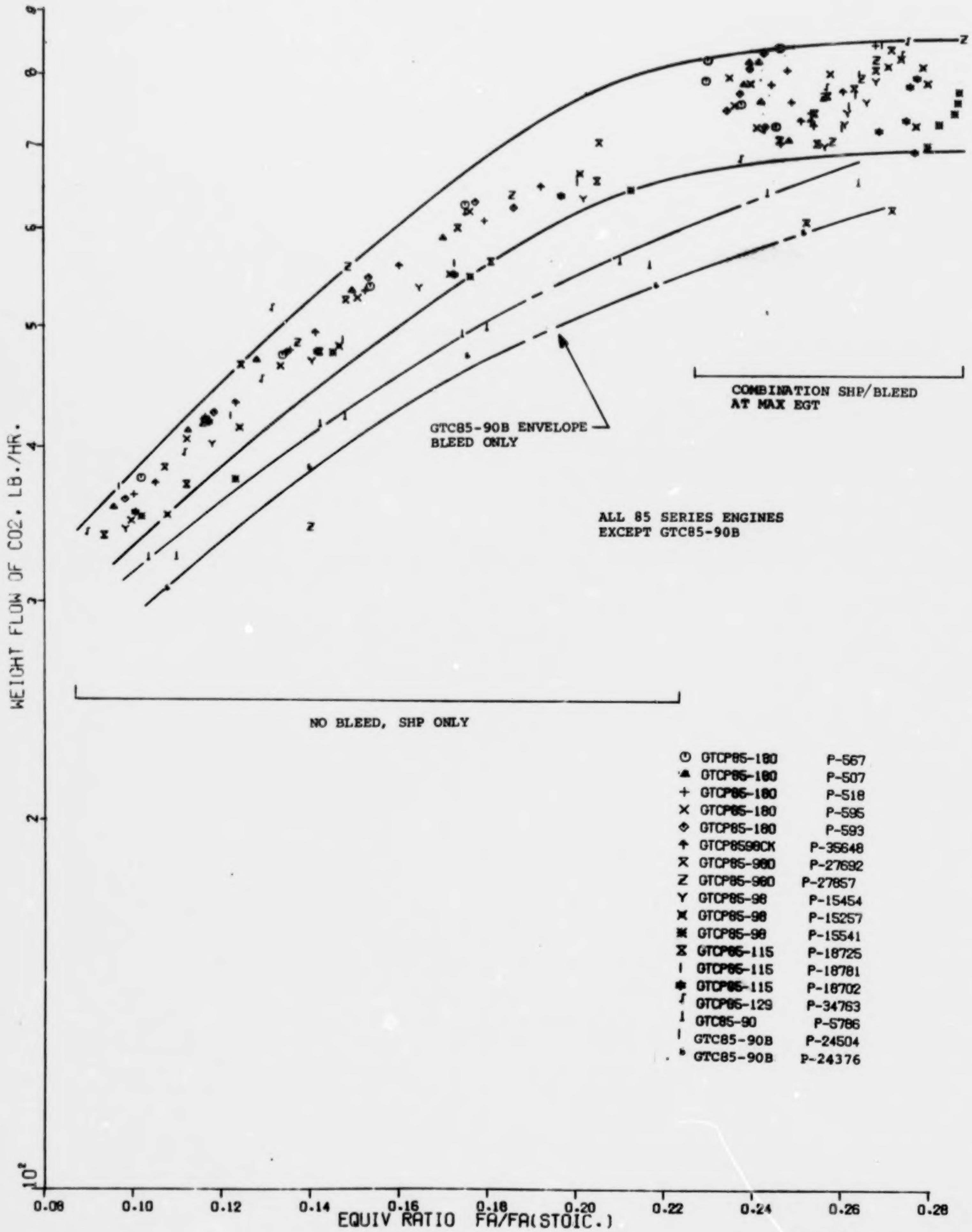

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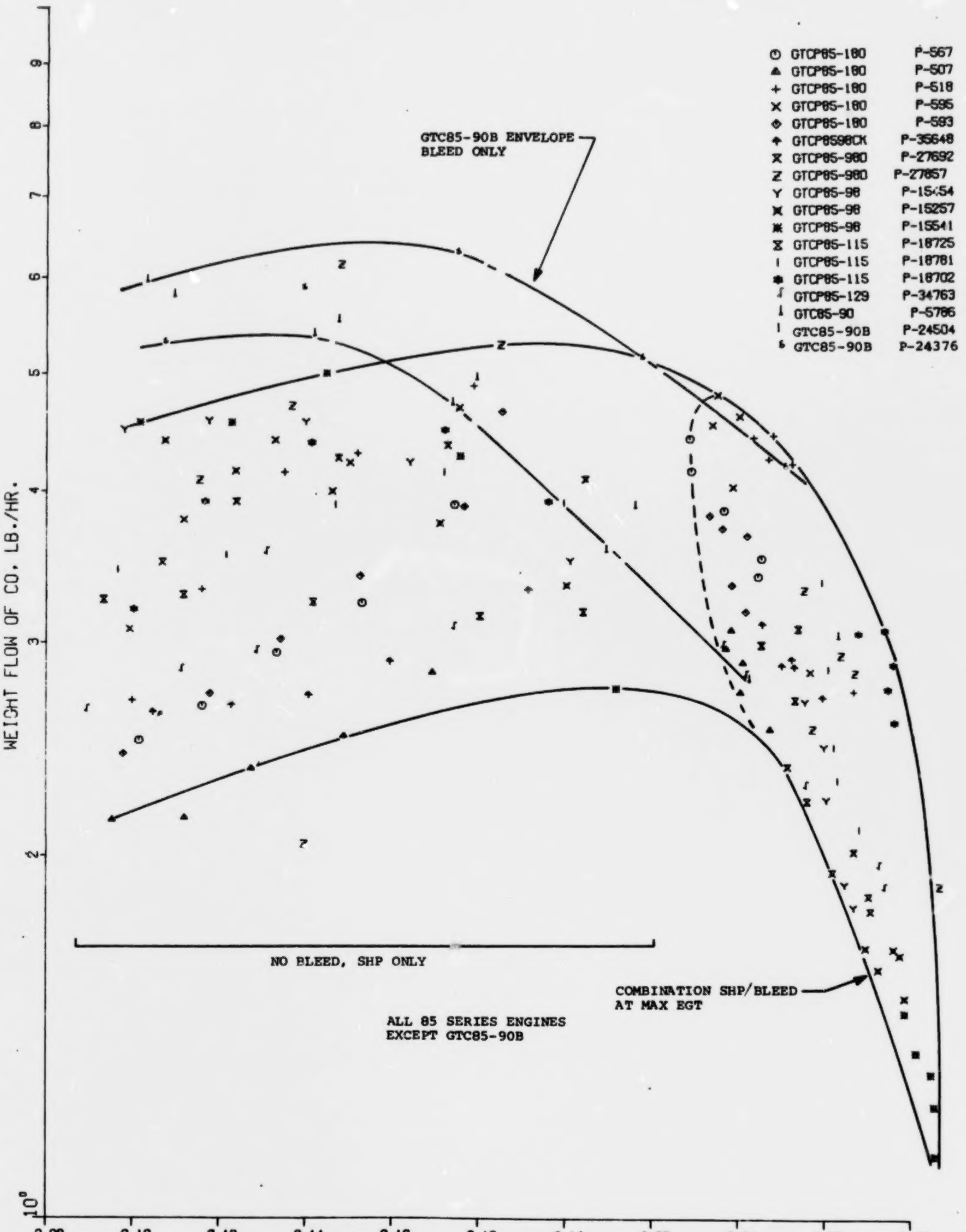

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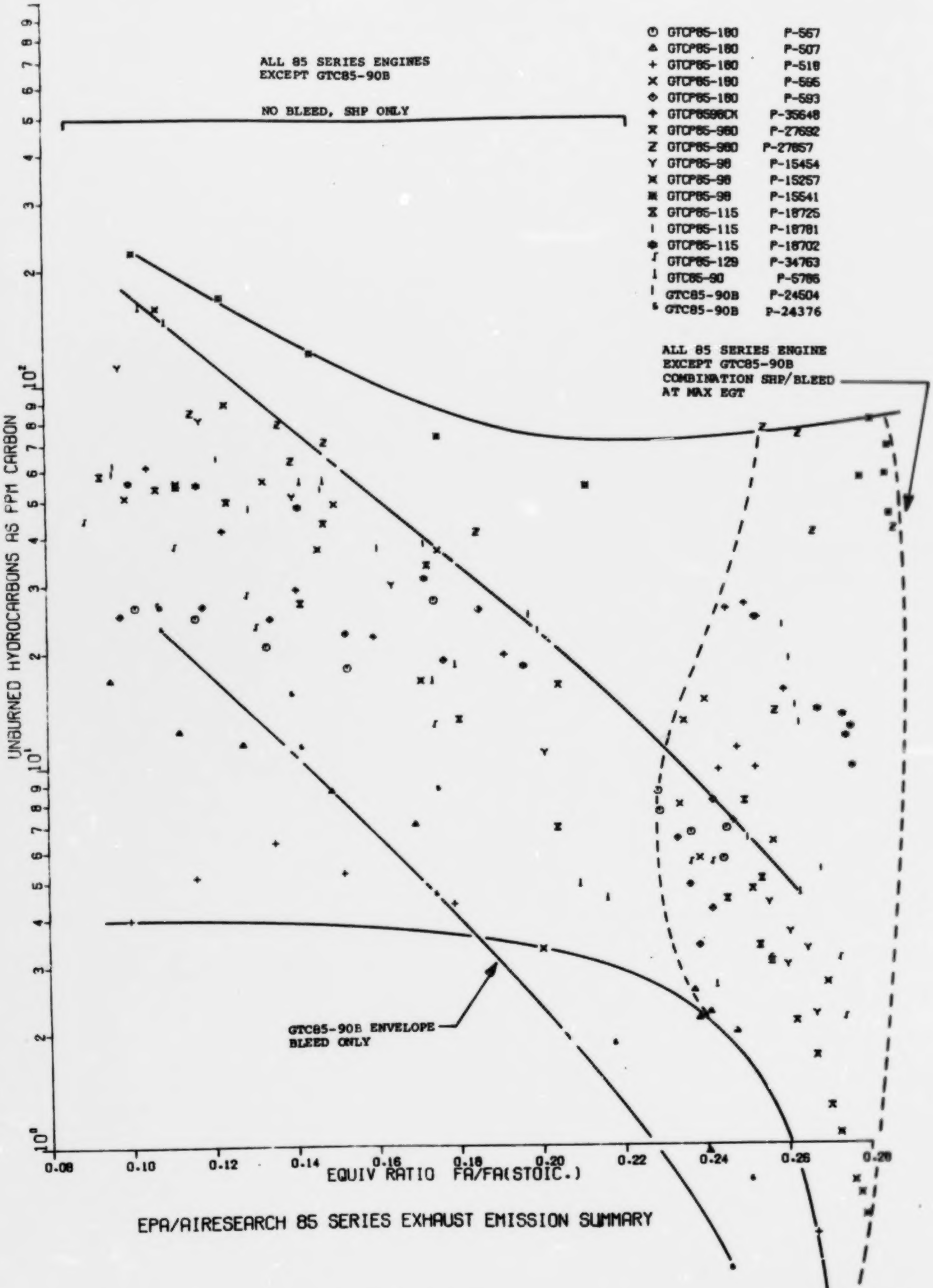

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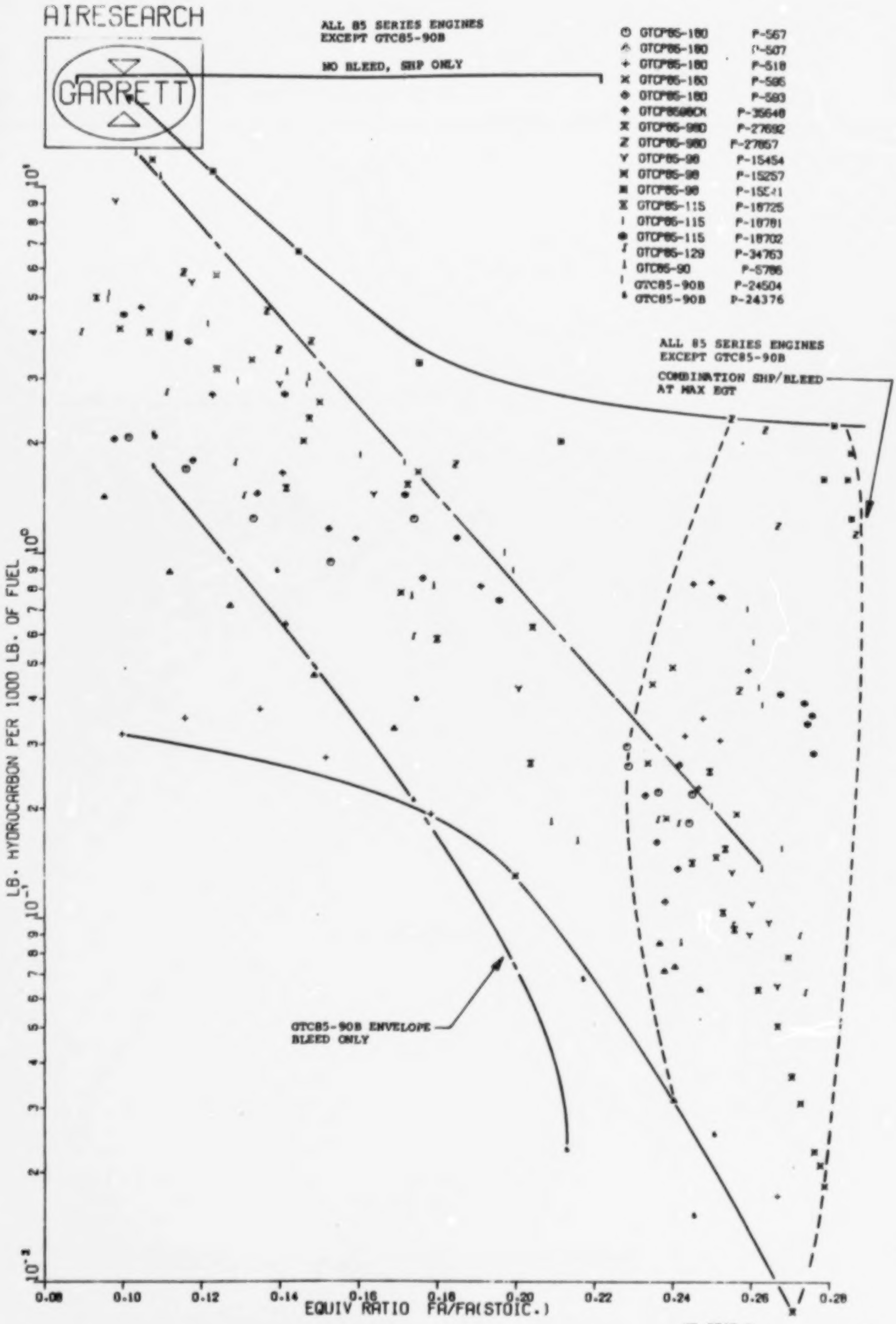

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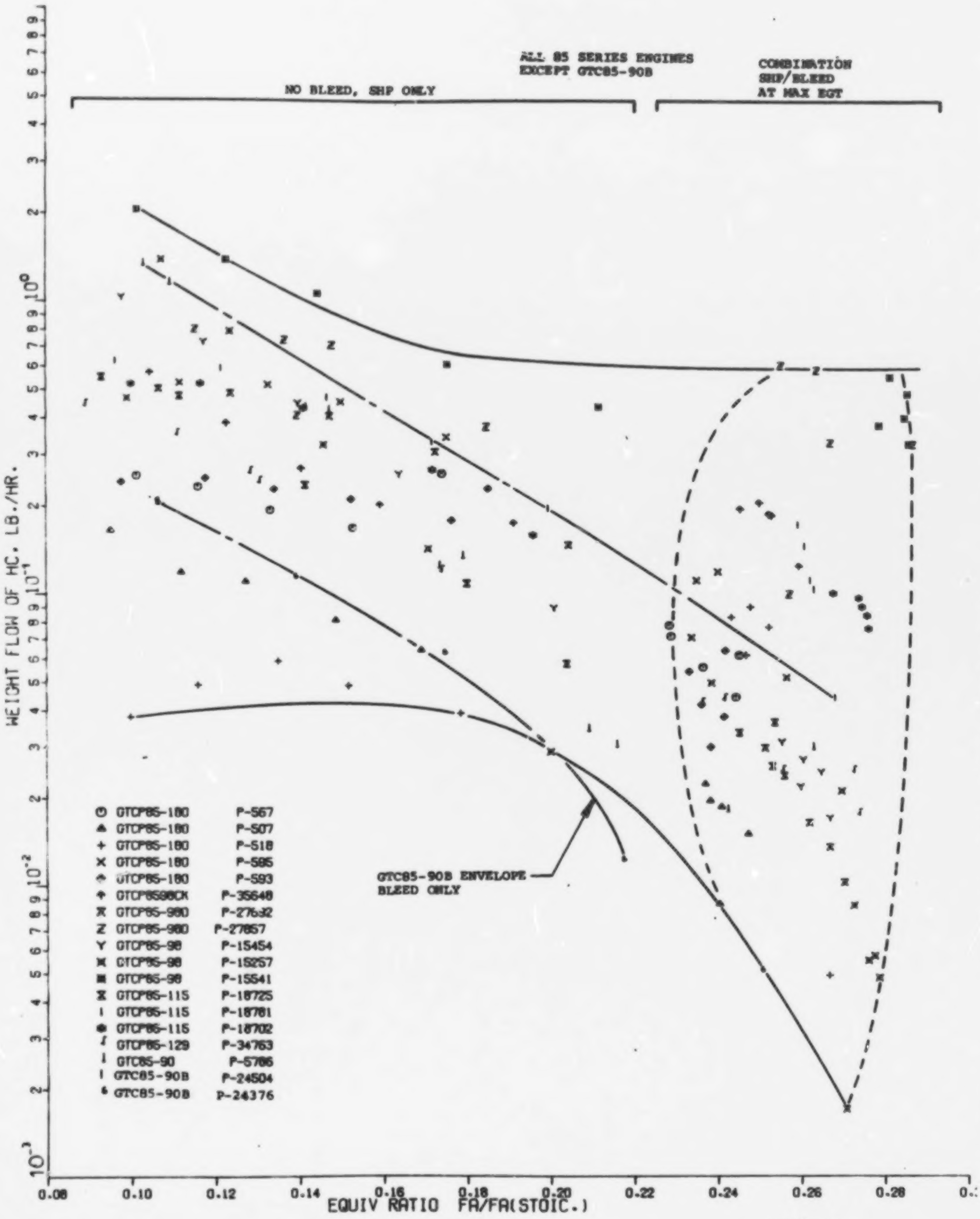

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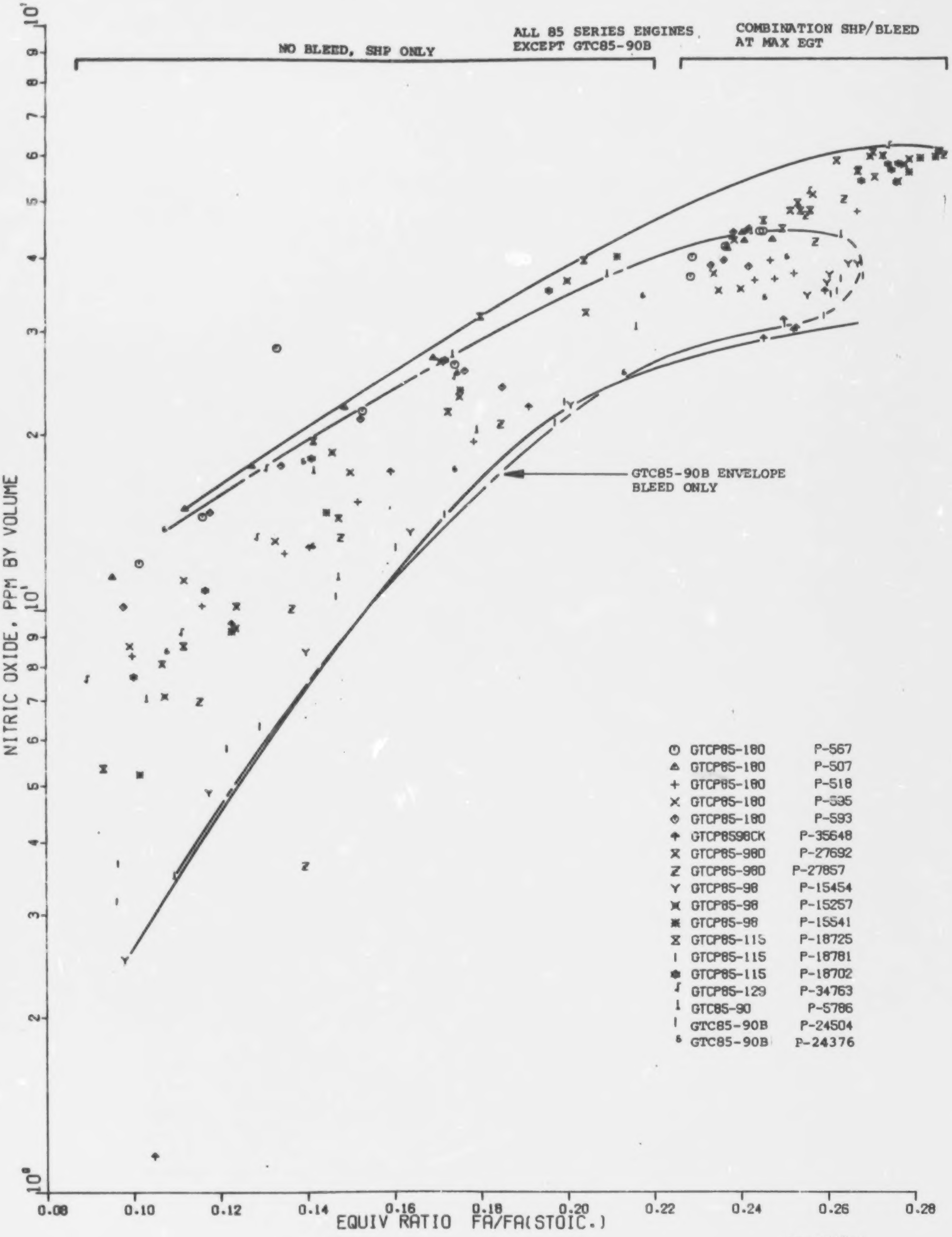

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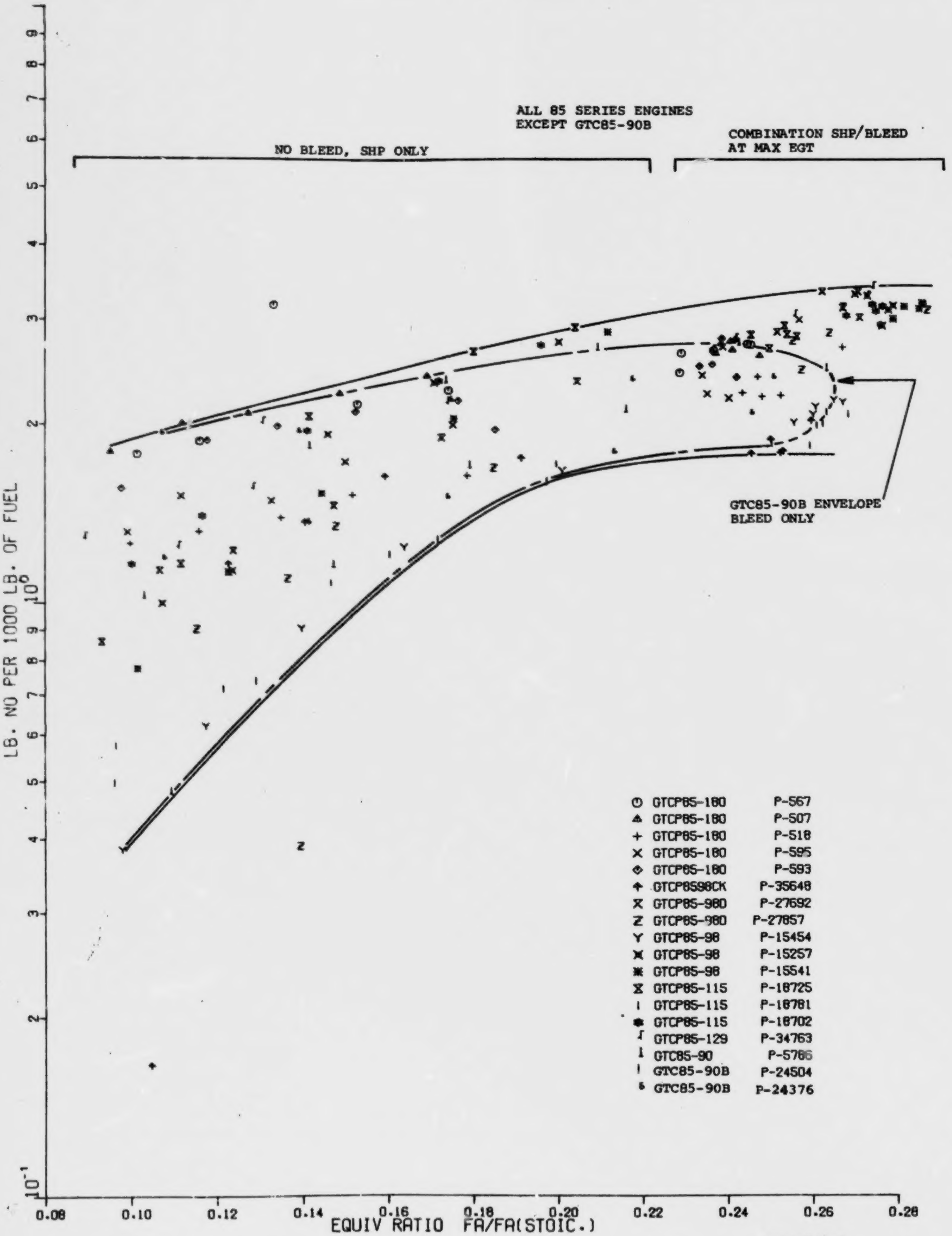

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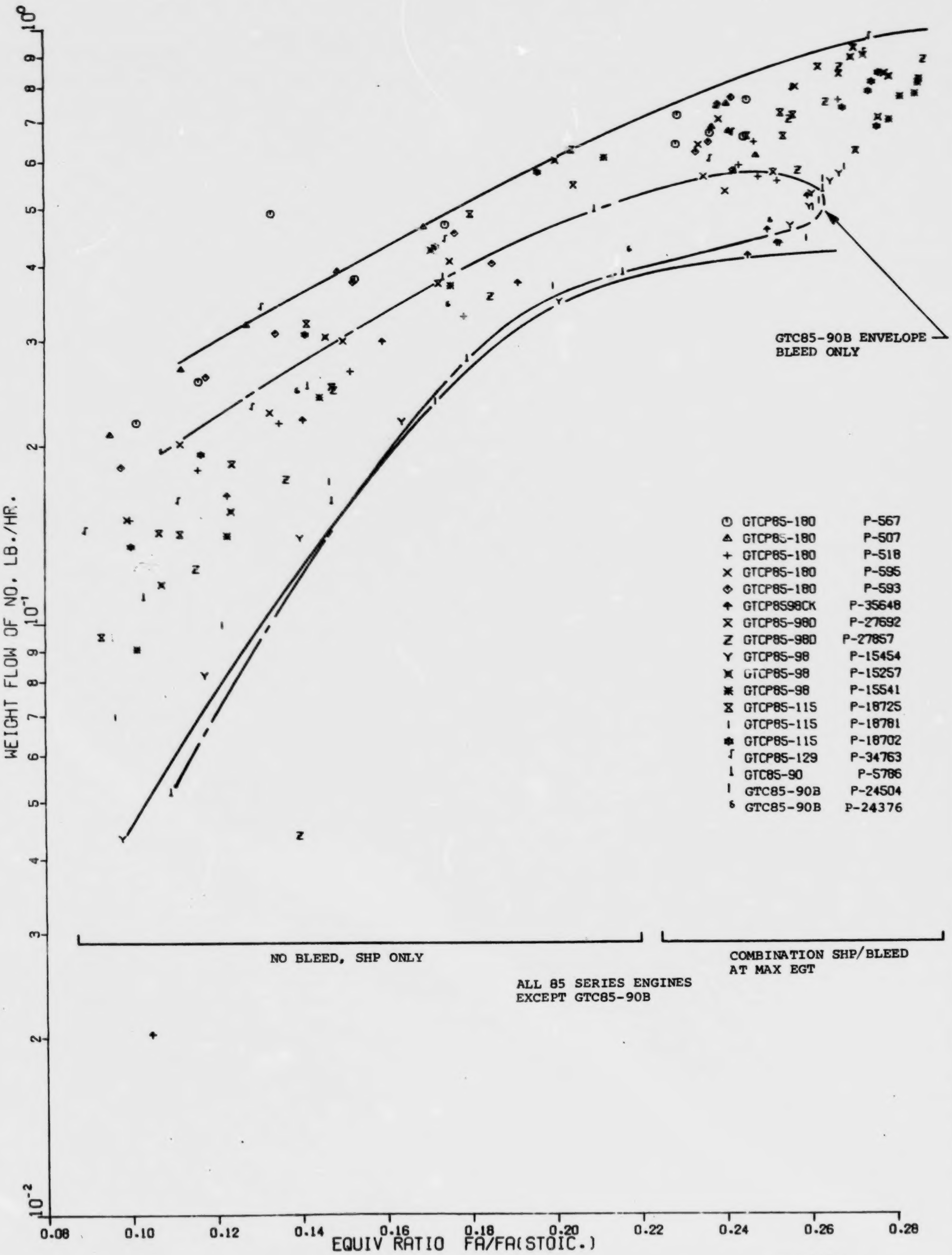

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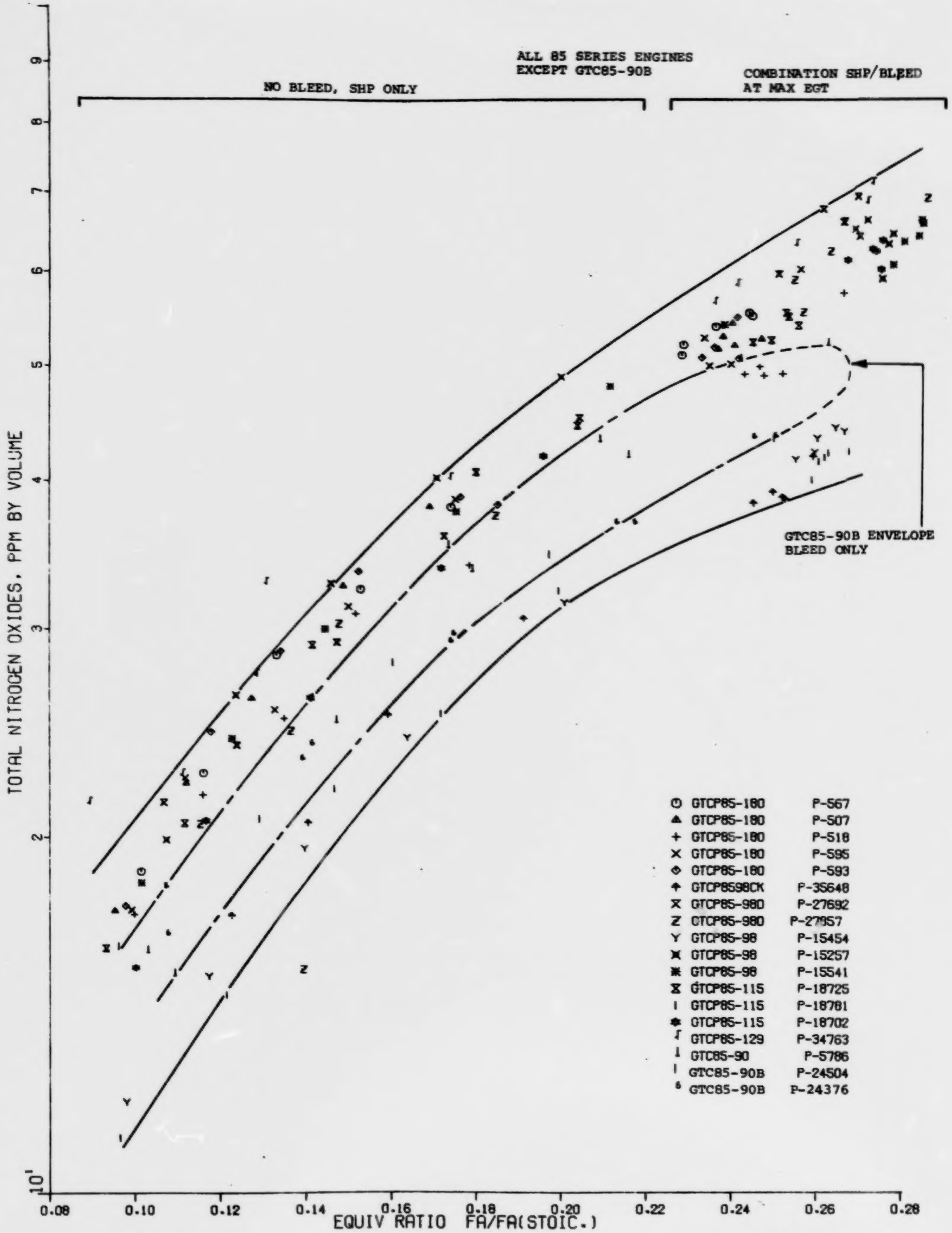

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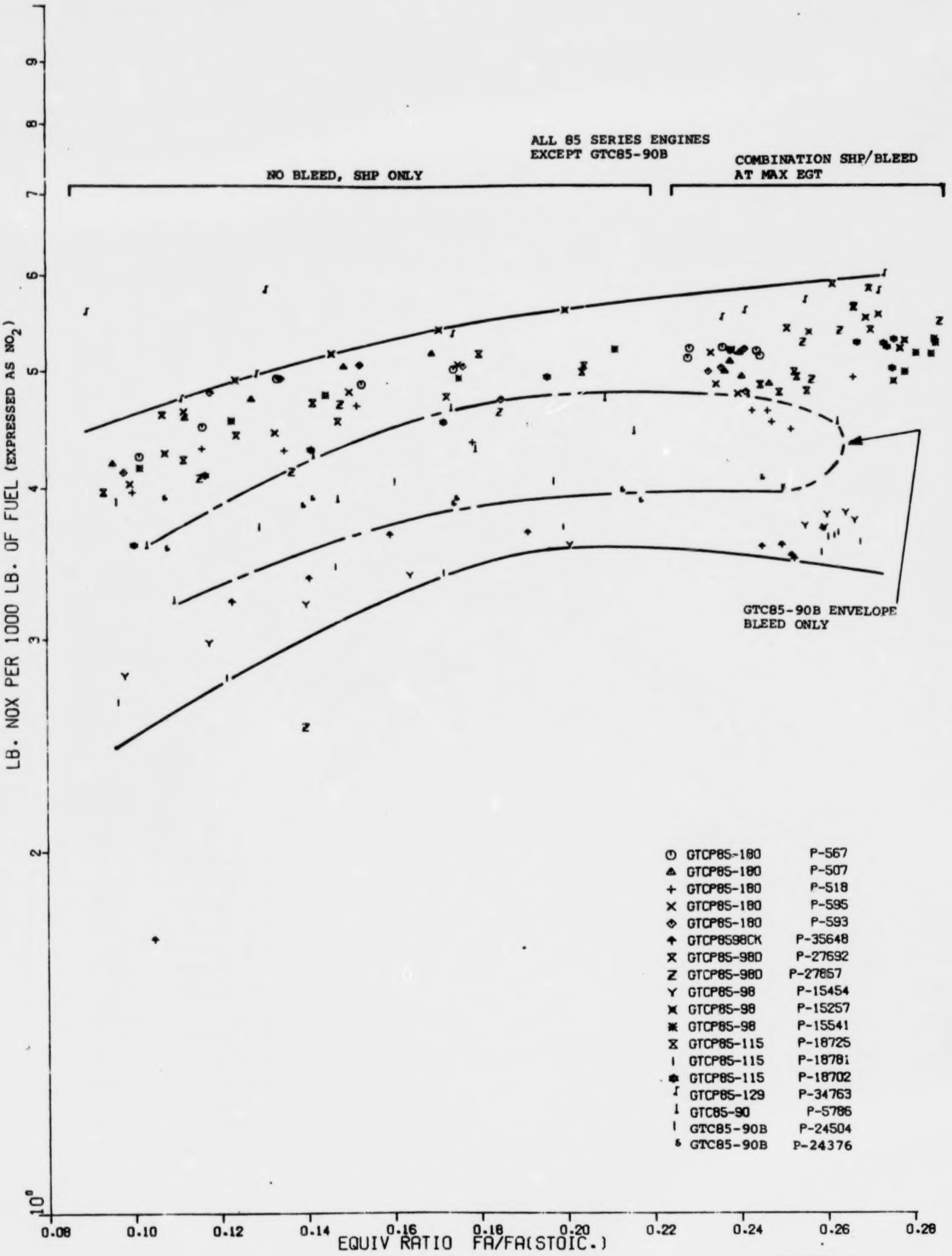

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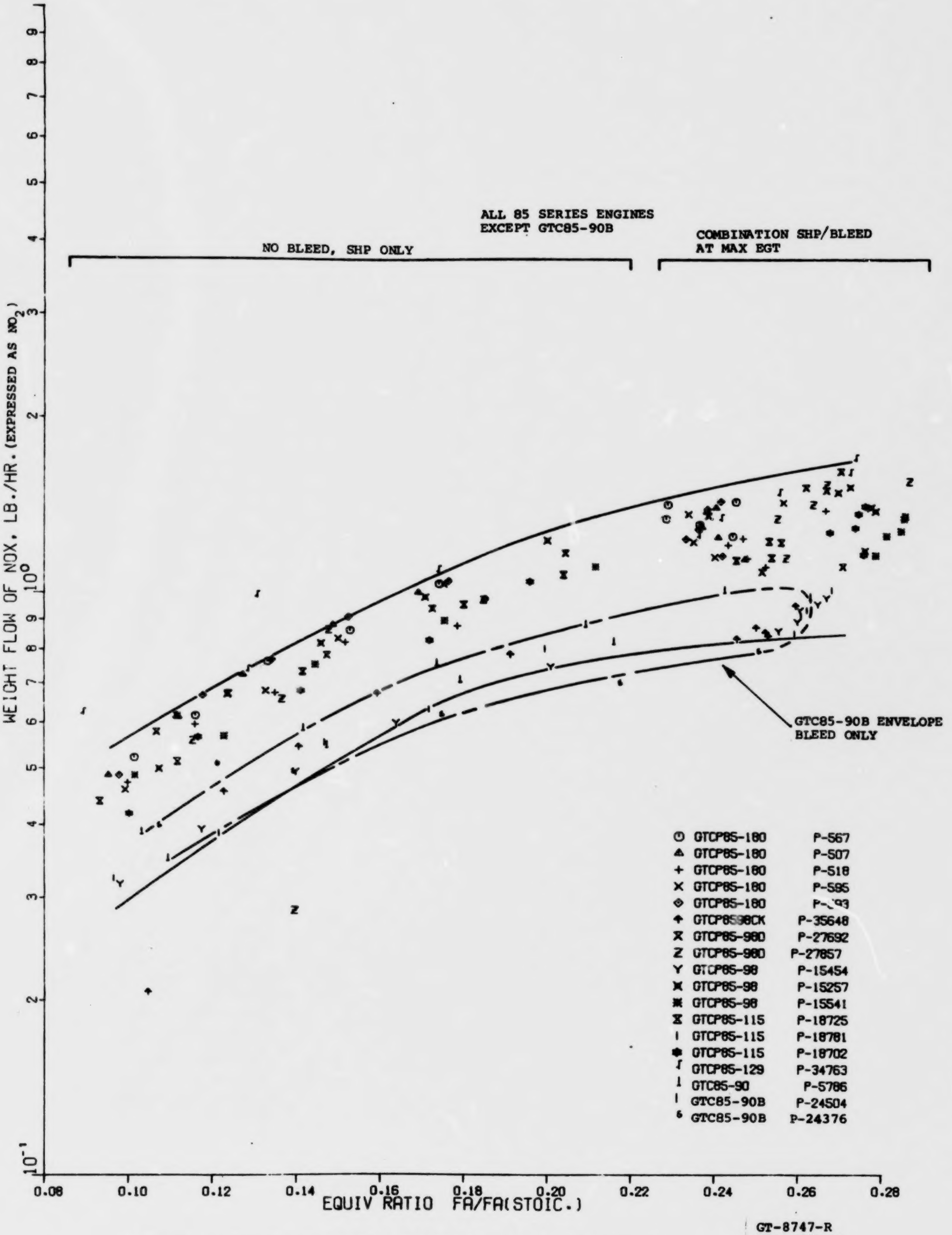
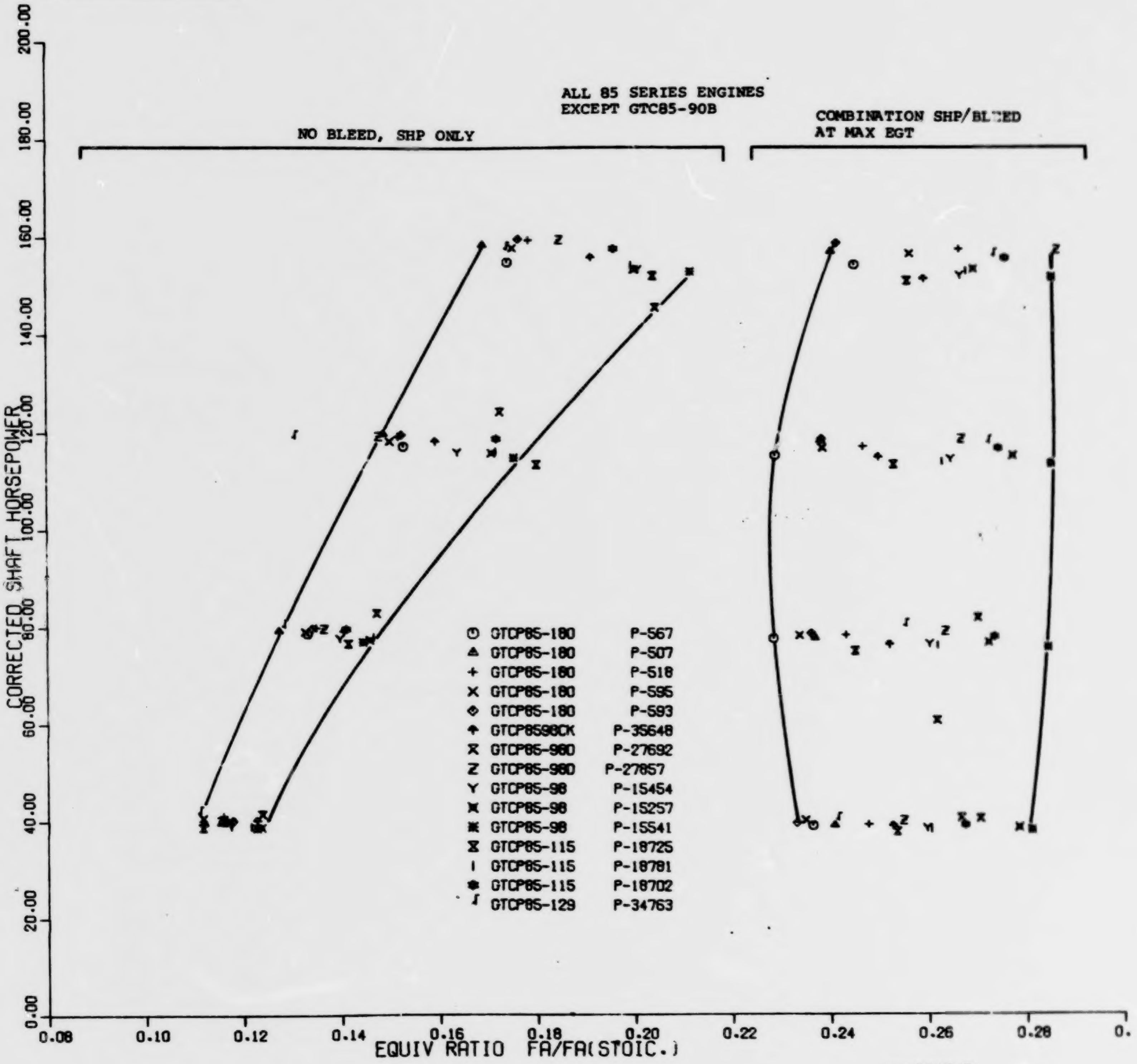
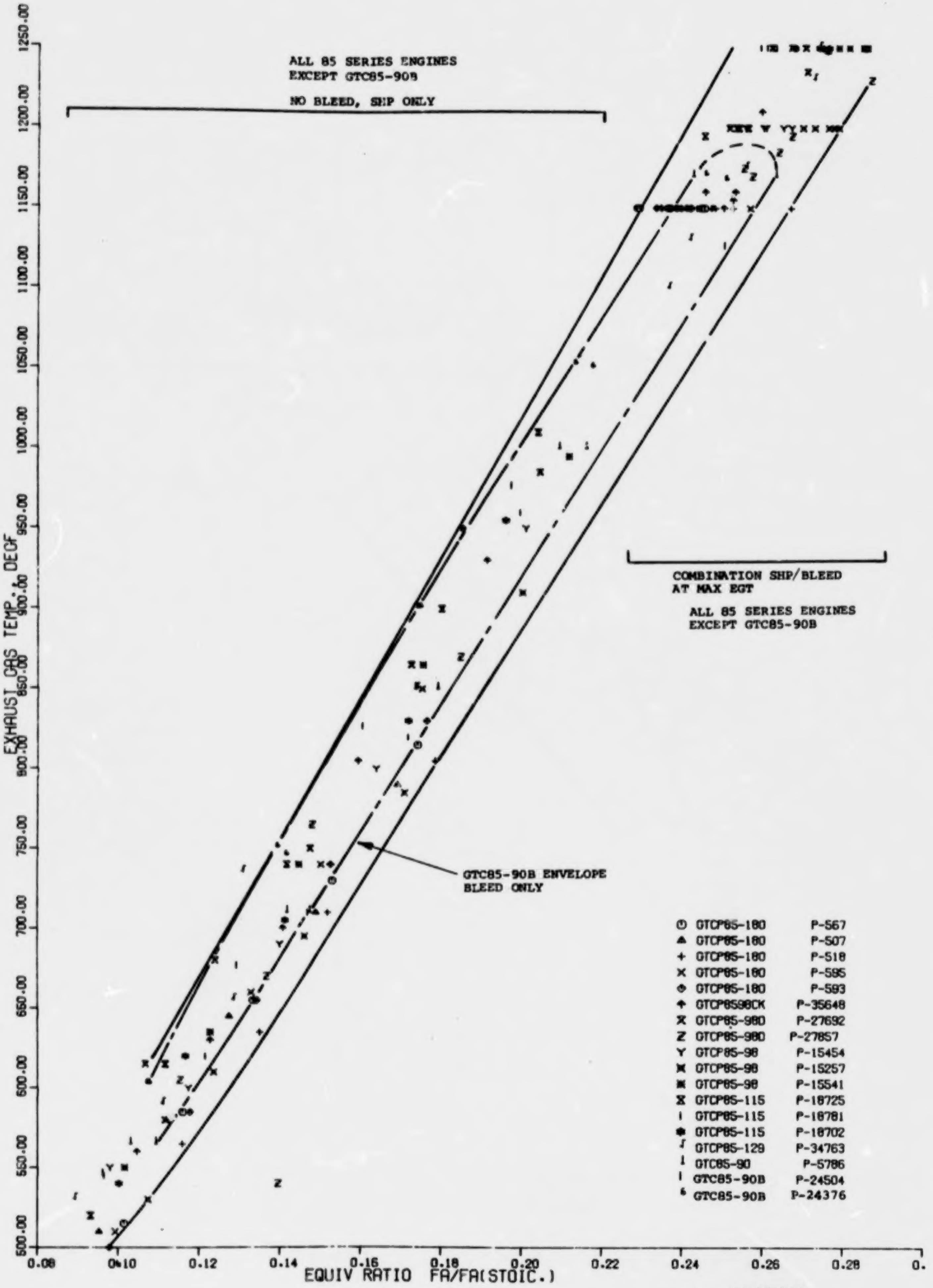


EPA/AIRESEARCH 85 SERIES EXHAUST EMISSION SUMMARY

AIRESEARCH



EPA/AIRESEARCH 85 SERIES EXHAUST EMISSION SUMMARY



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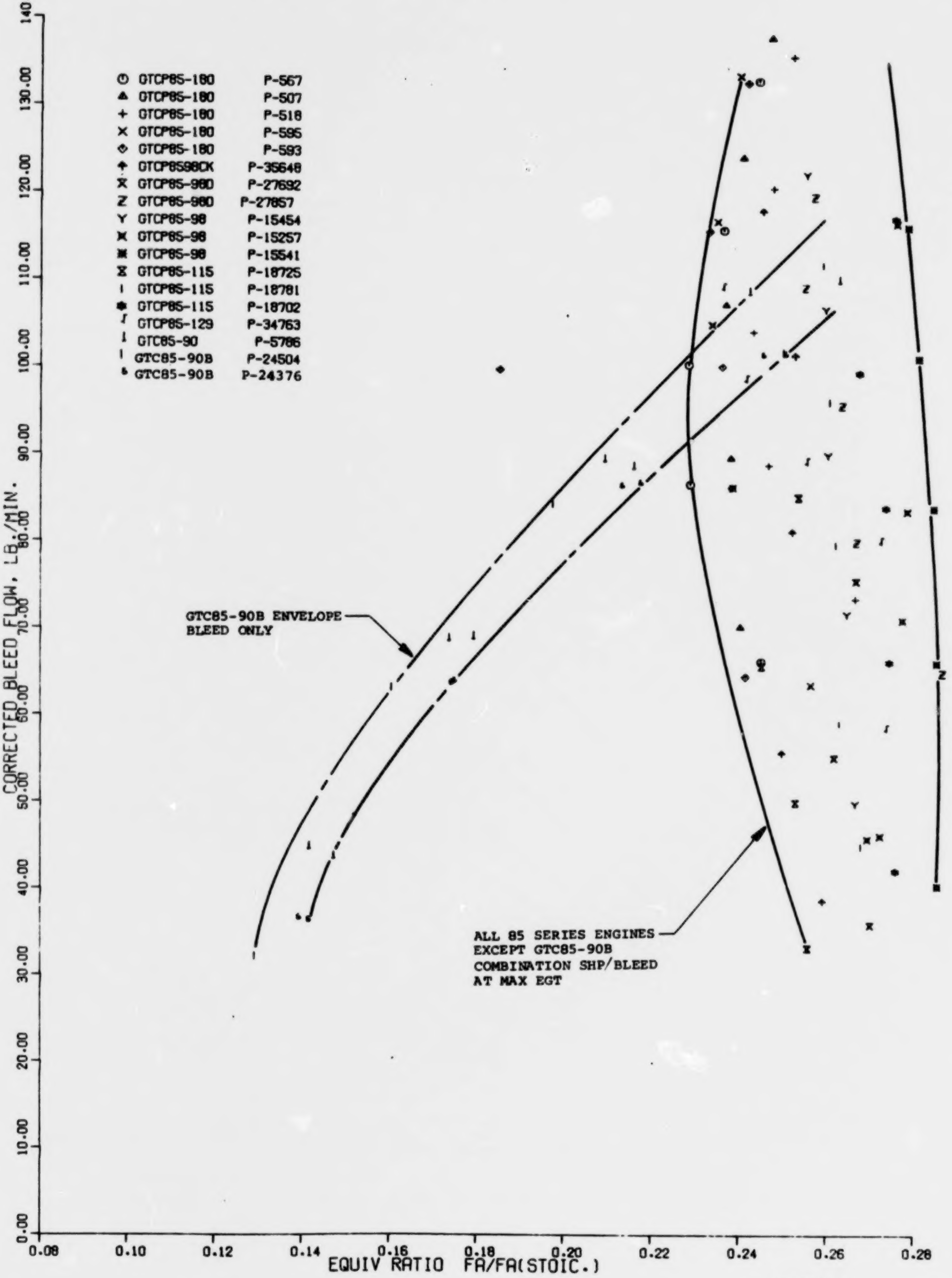
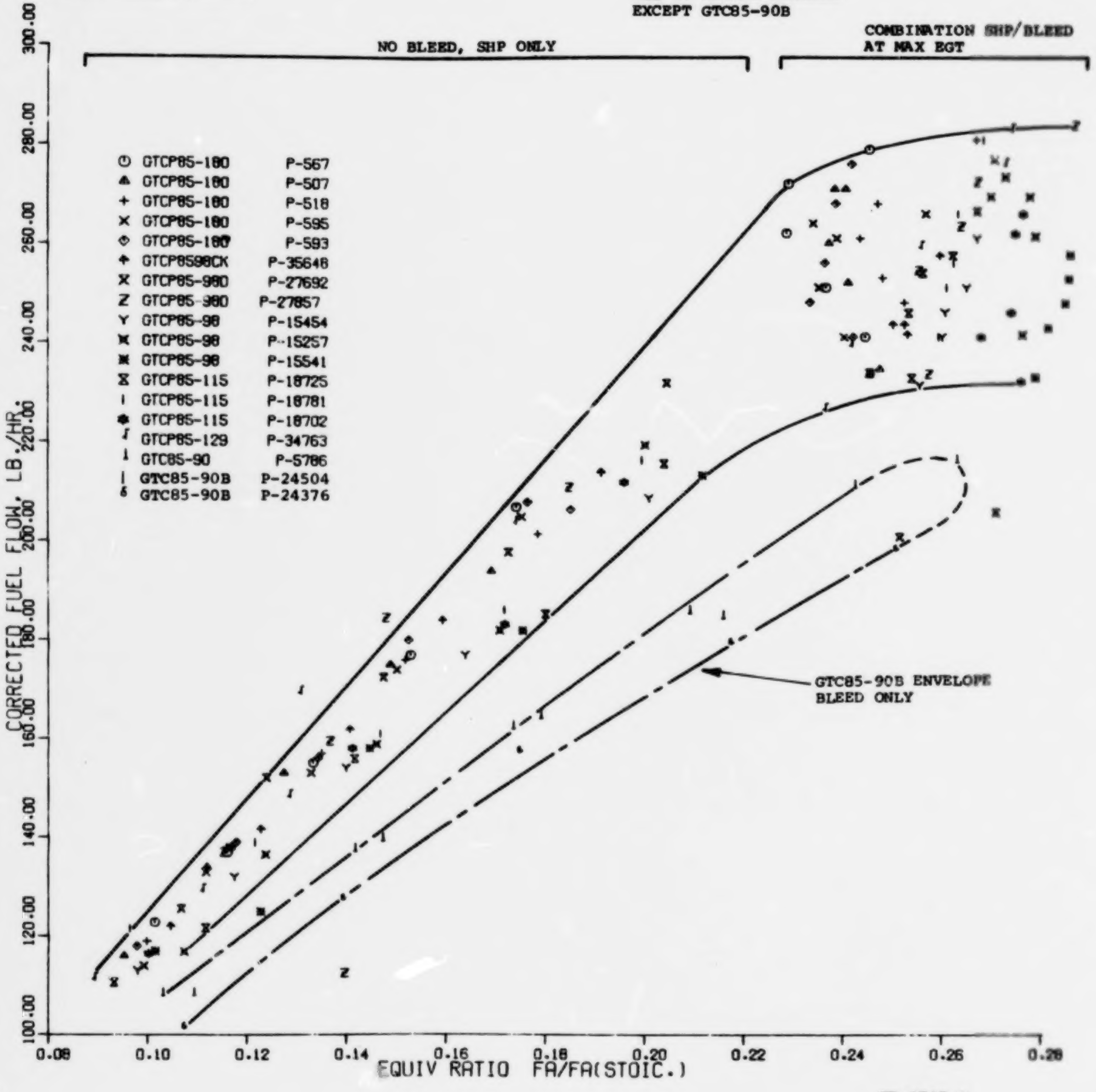


EPA/AIRESEARCH 85 SERIES EXHAUST EMISSION SUMMARY

AIRESEARCH

GARRETT



EPA/AIRESEARCH 85 SERIES EXHAUST EMISSION SUMMARY

GROUP 4

LARGE AUXILIARY POWER UNITS

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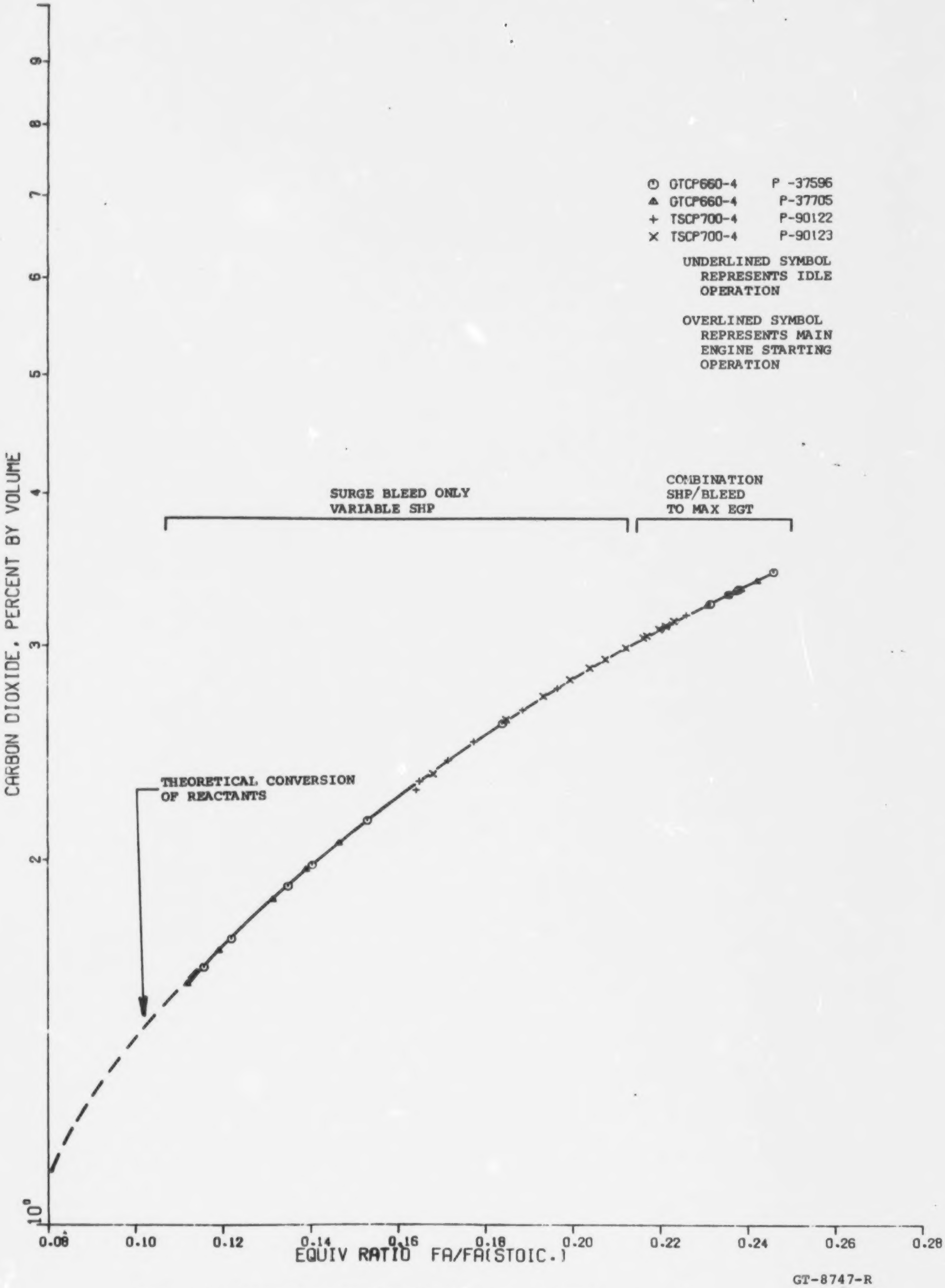
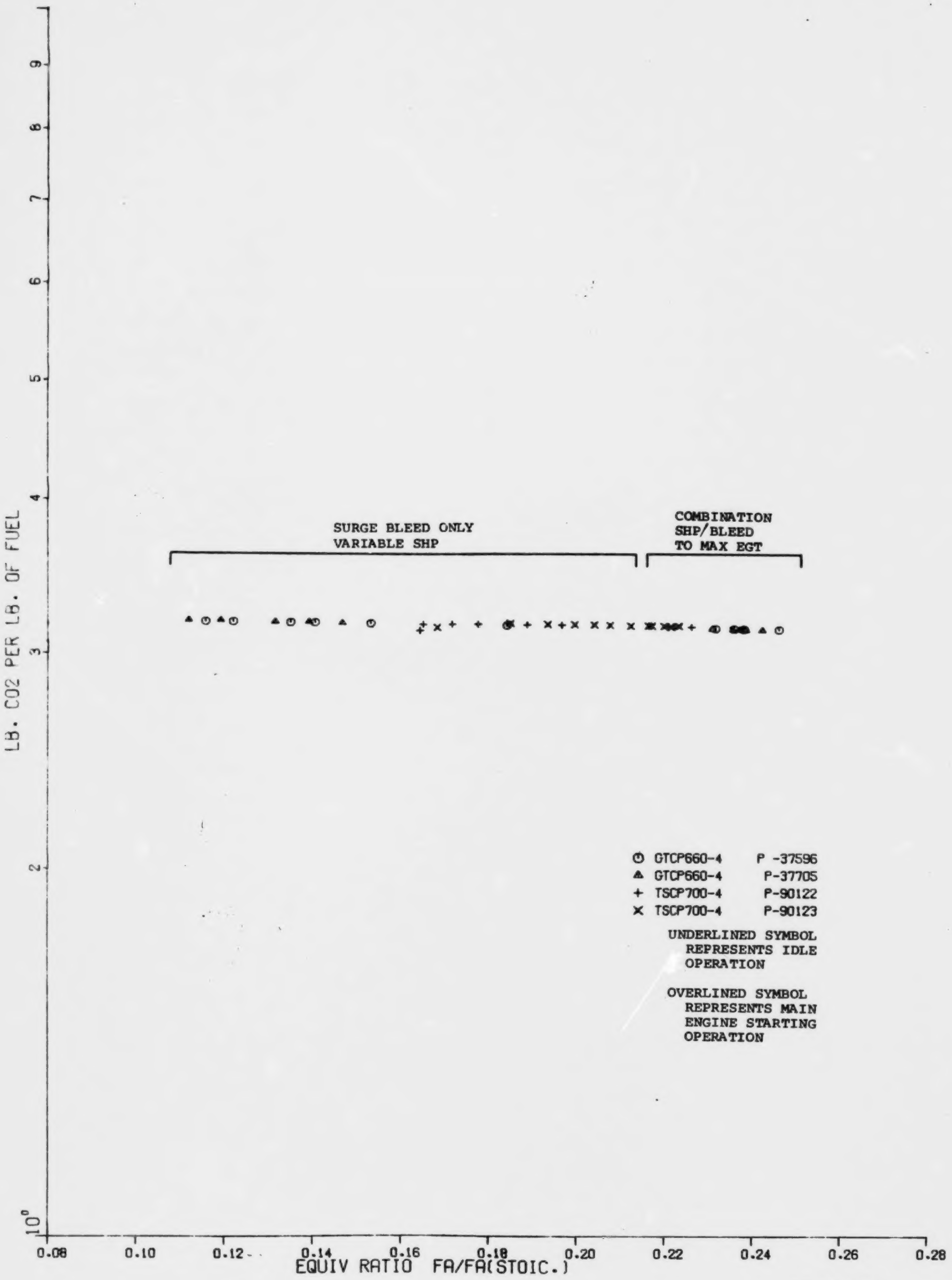


EPA / AIRESEARCH LARGE APU EXHAUST EMISSION SUMMARY



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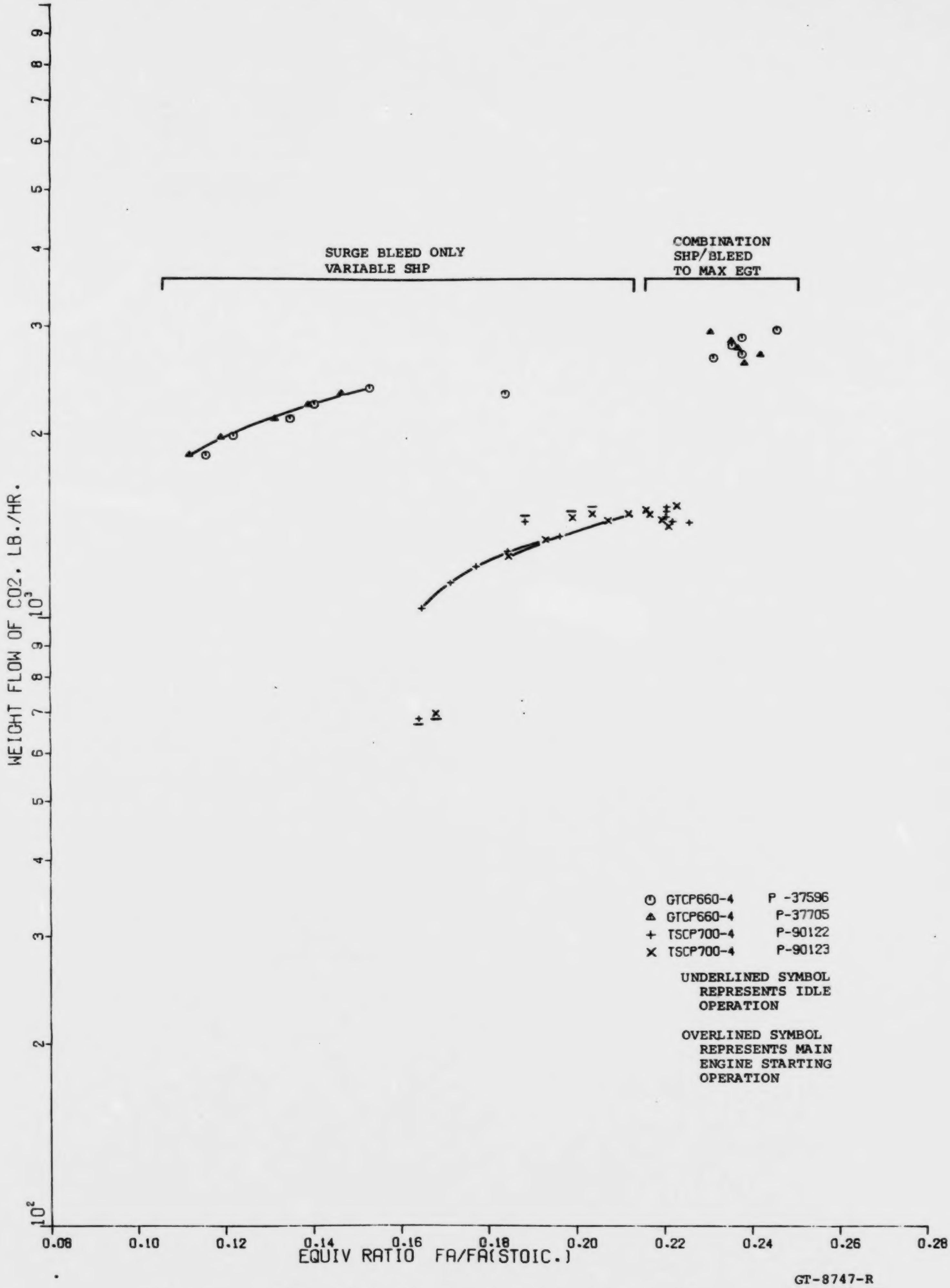
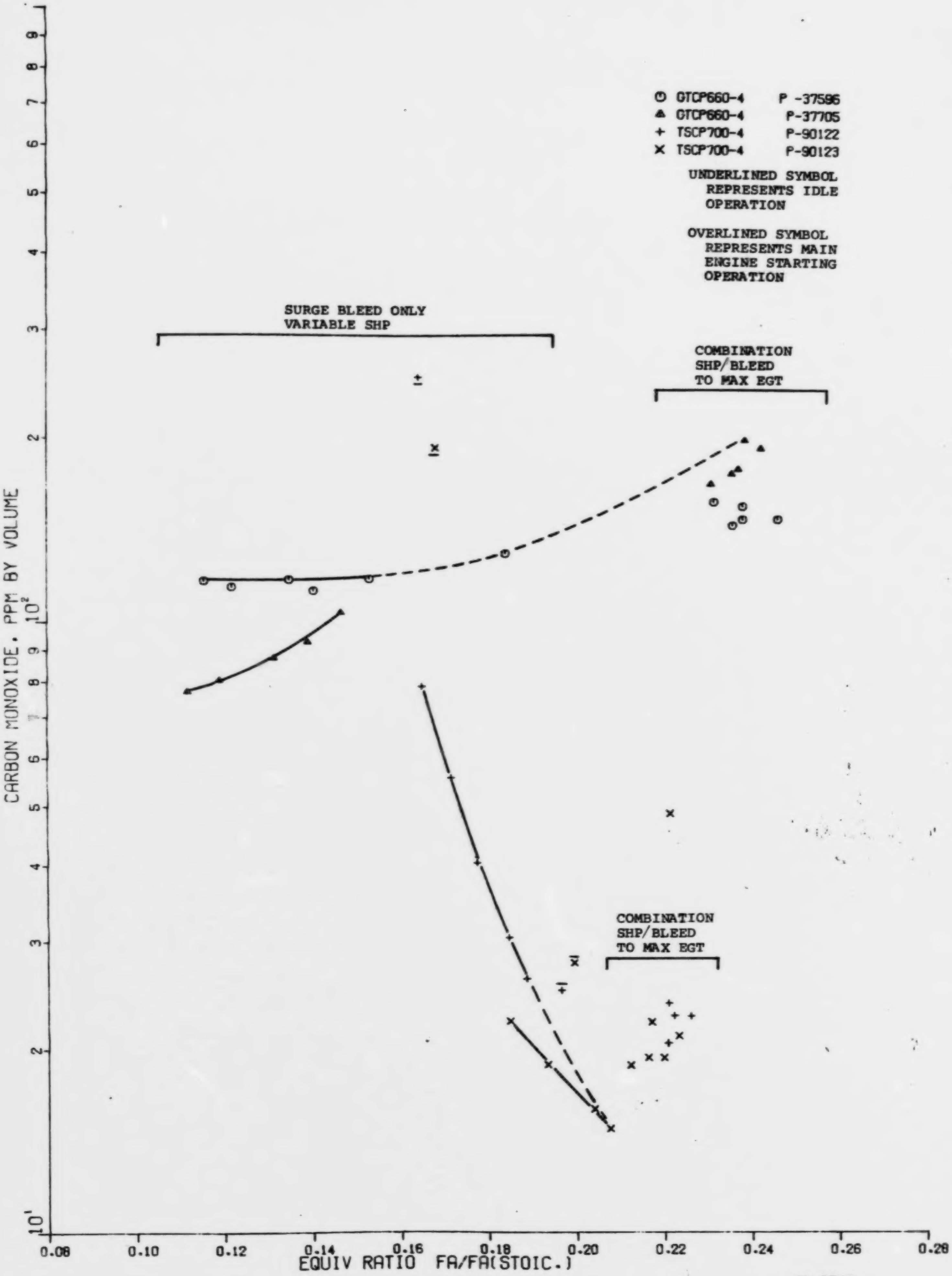


UNDERLINED SYMBOL REPRESENTS IDLE OPERATION

OVERLINED SYMBOL REPRESENTS MAIN ENGINE STARTING OPERATION

EPA / AIRESEARCH LARGE APU EXHAUST EMISSION SUMMARY



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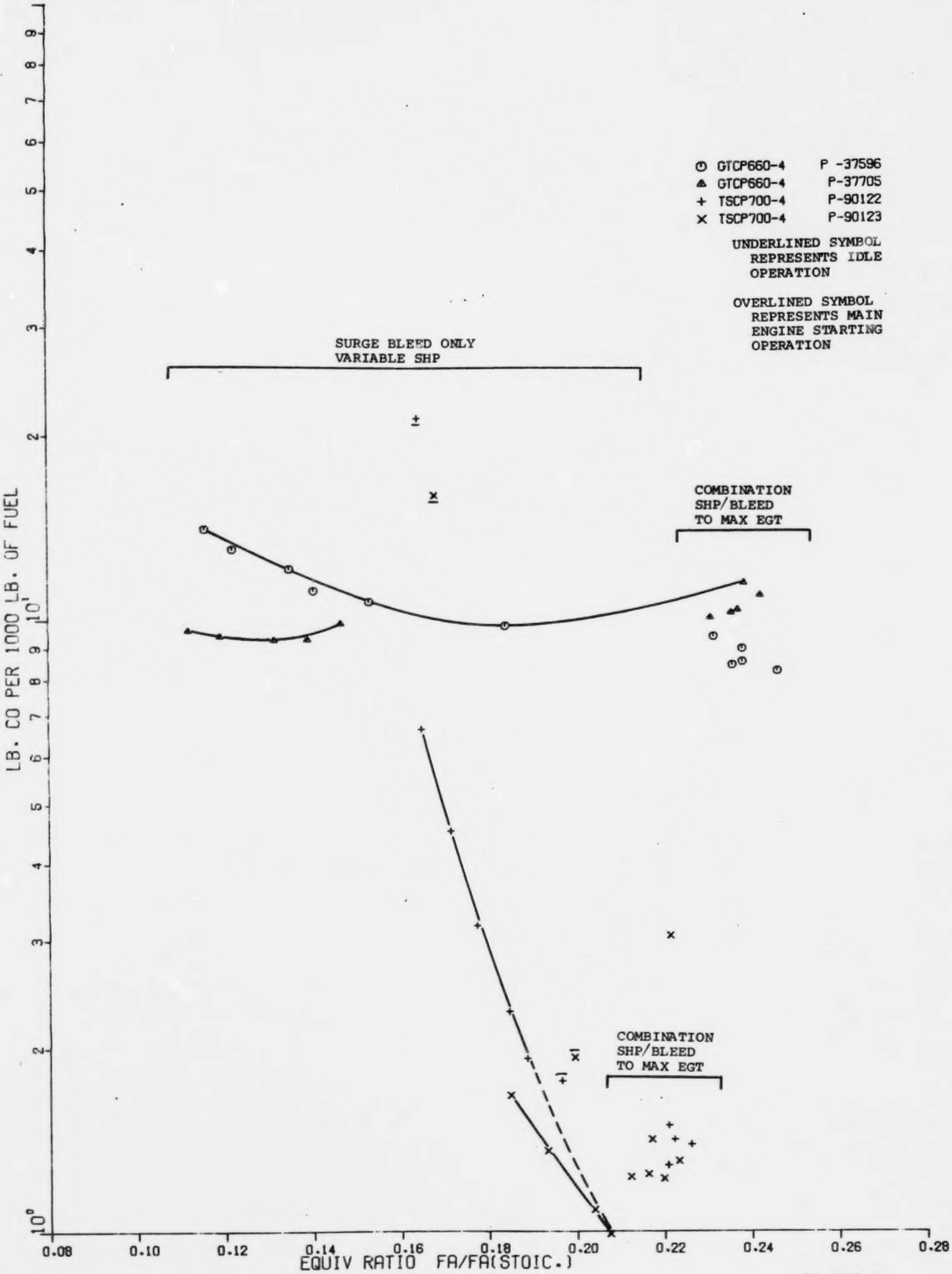

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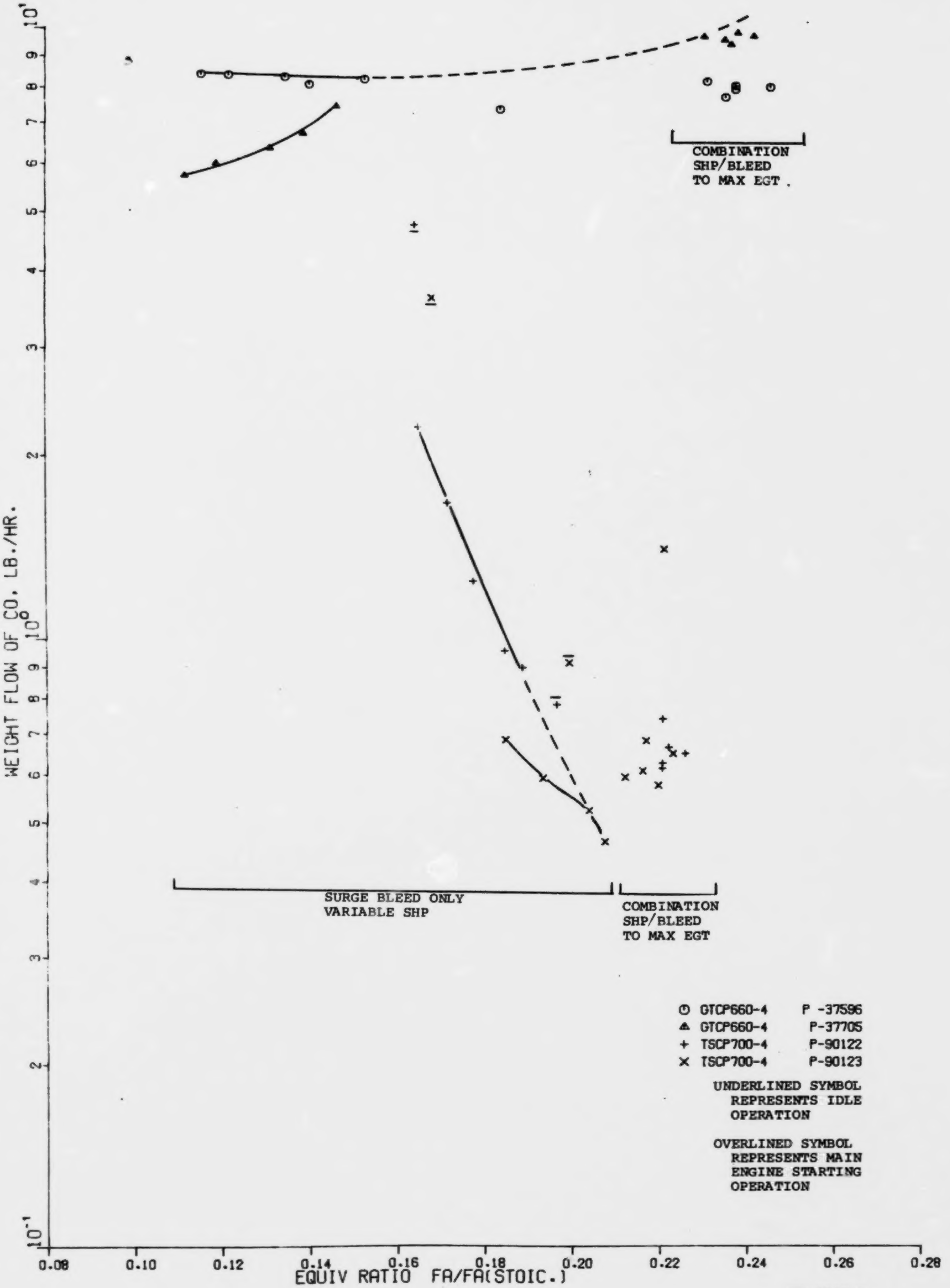

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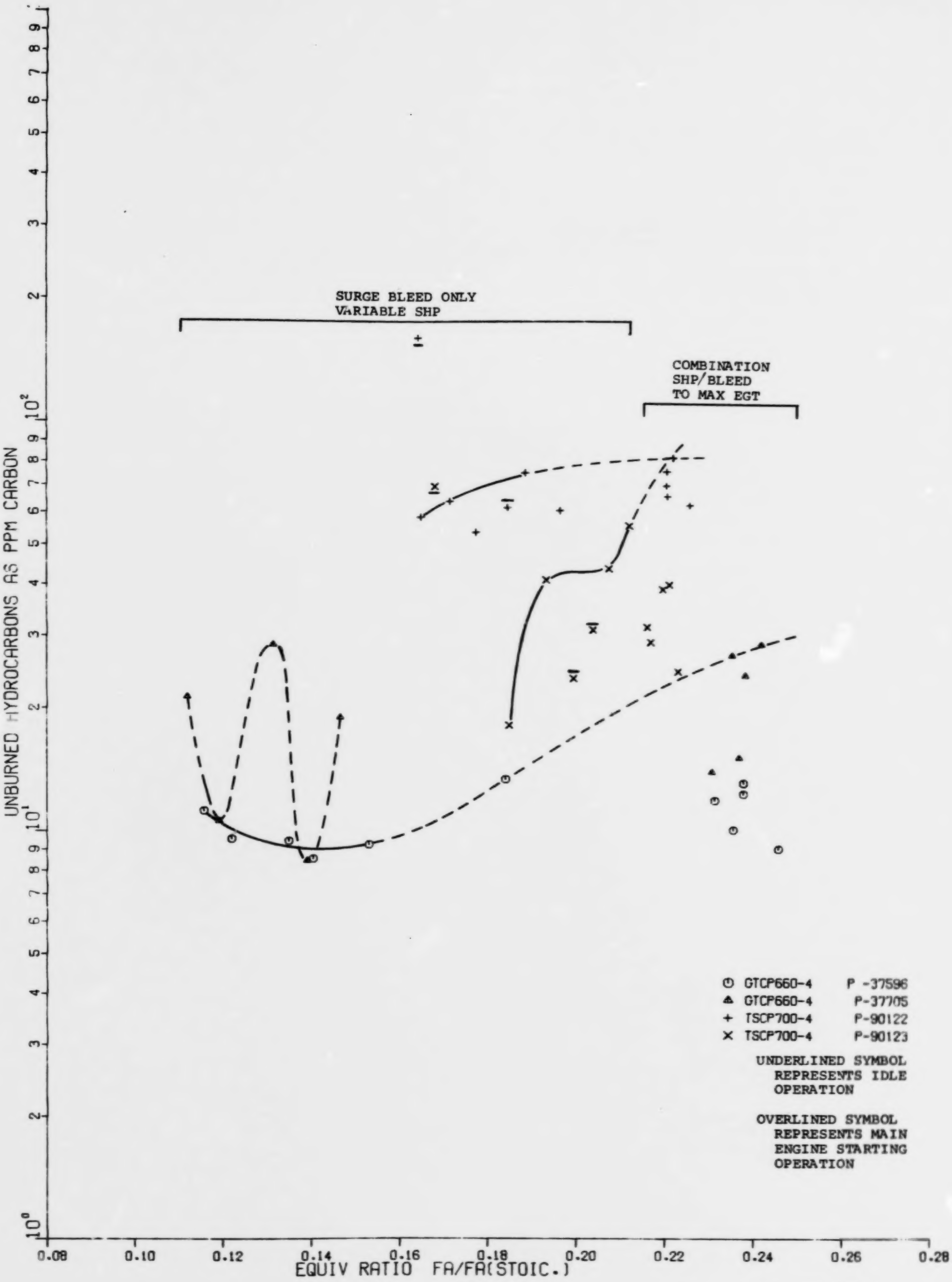
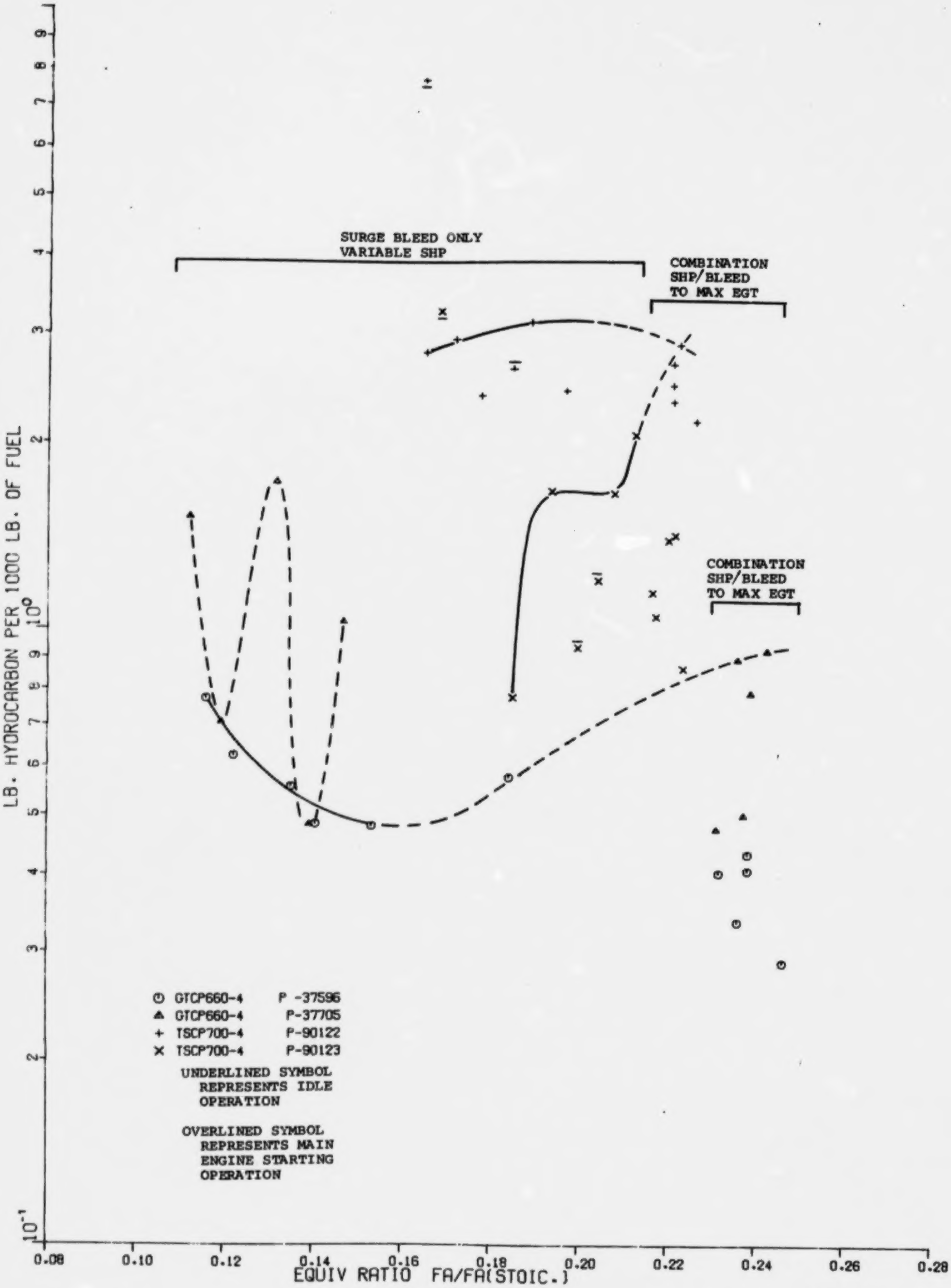


UNDERLINED SYMBOL REPRESENTS IDLE OPERATION

OVERLINED SYMBOL REPRESENTS MAIN ENGINE STARTING OPERATION

EPA / AIRESEARCH LARGE APU EXHAUST EMISSION SUMMARY



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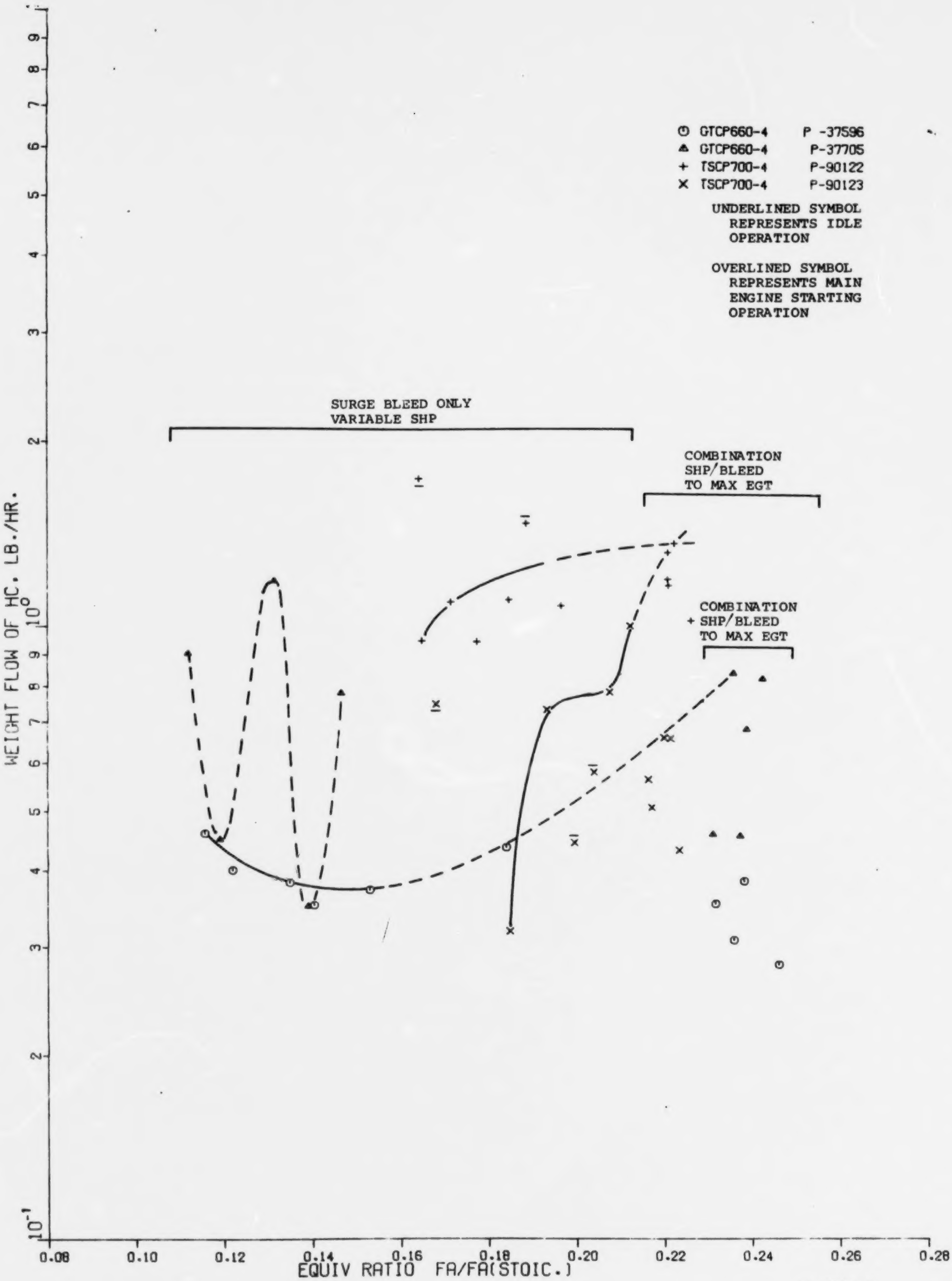

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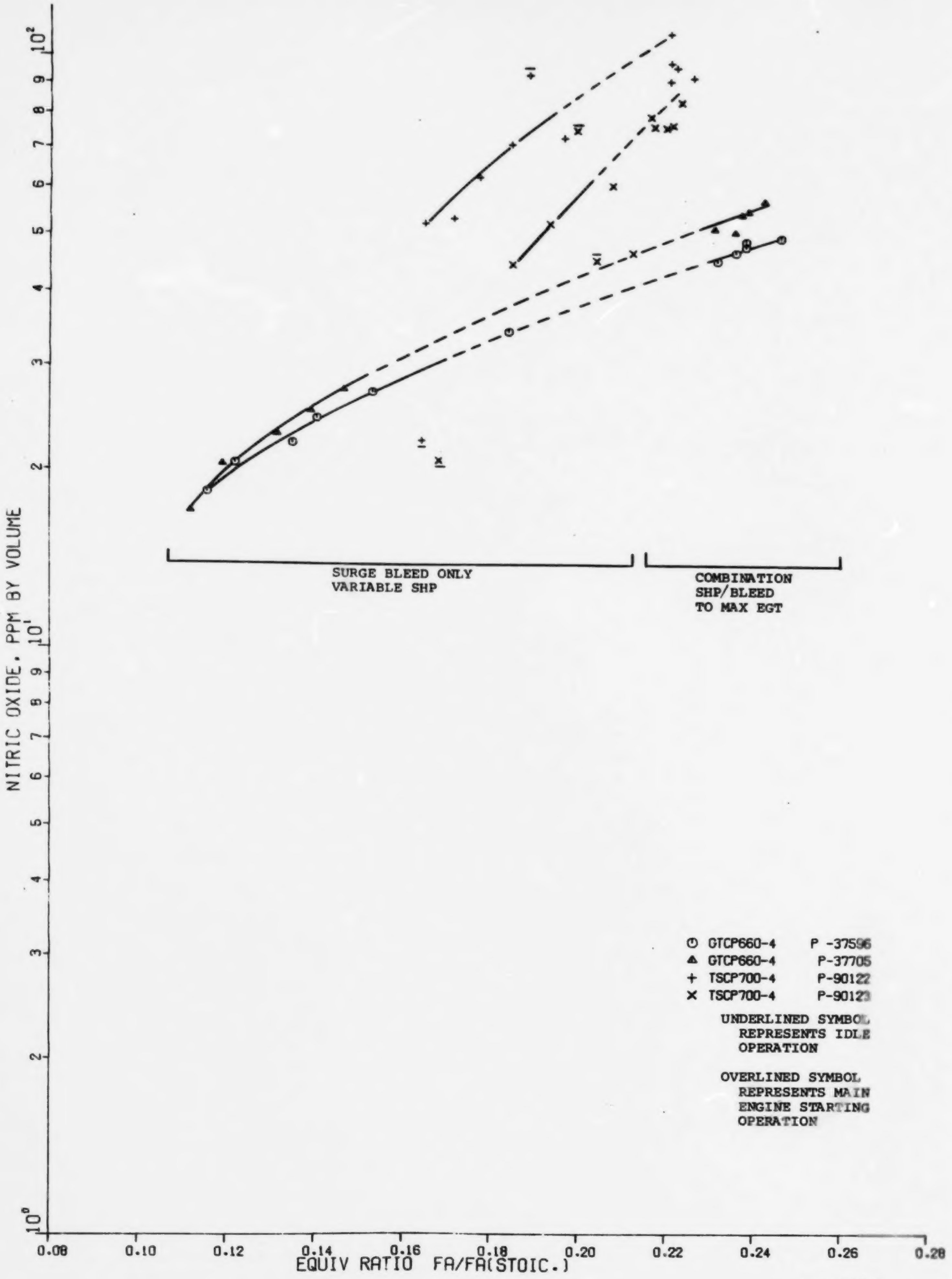

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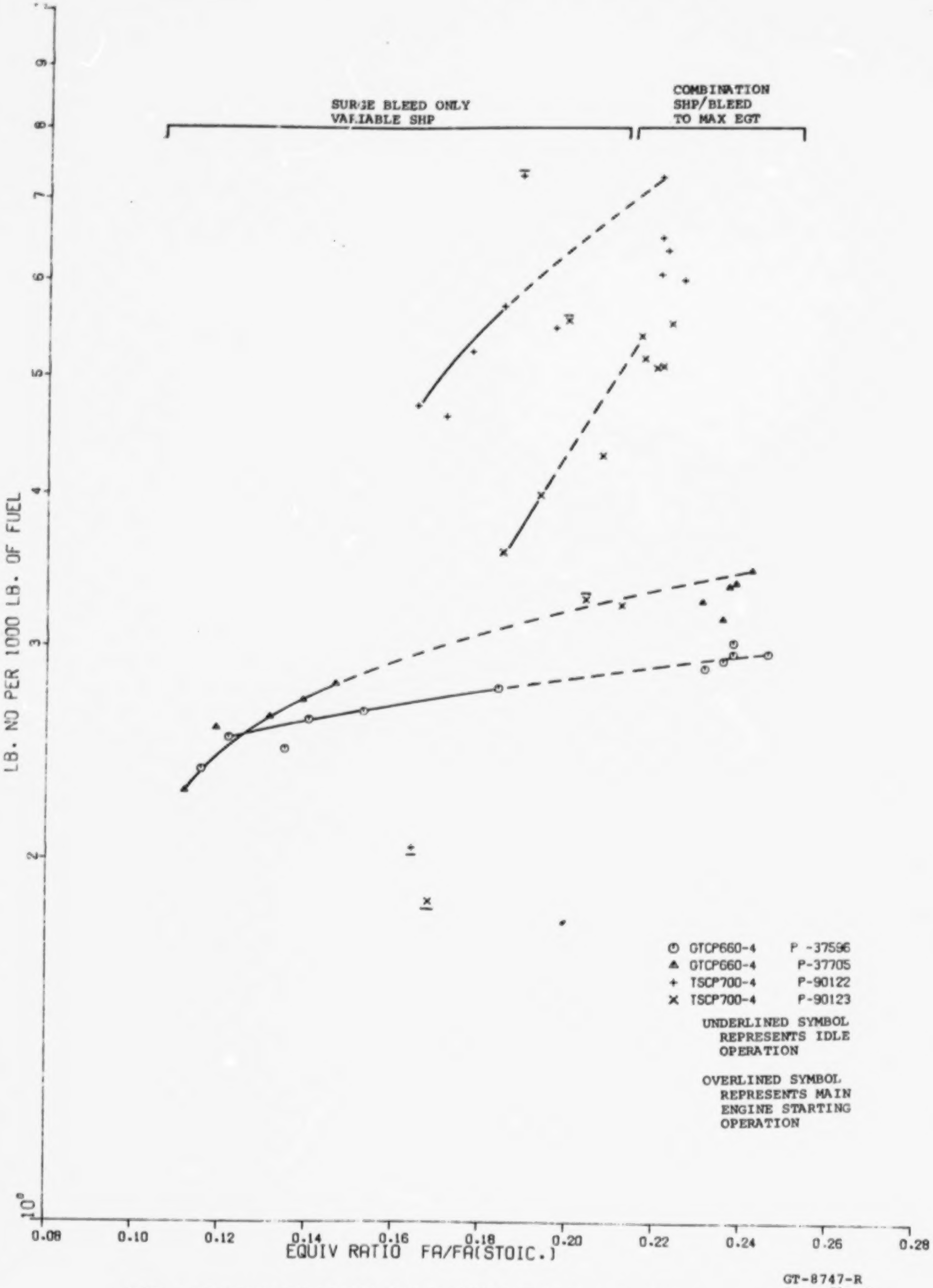

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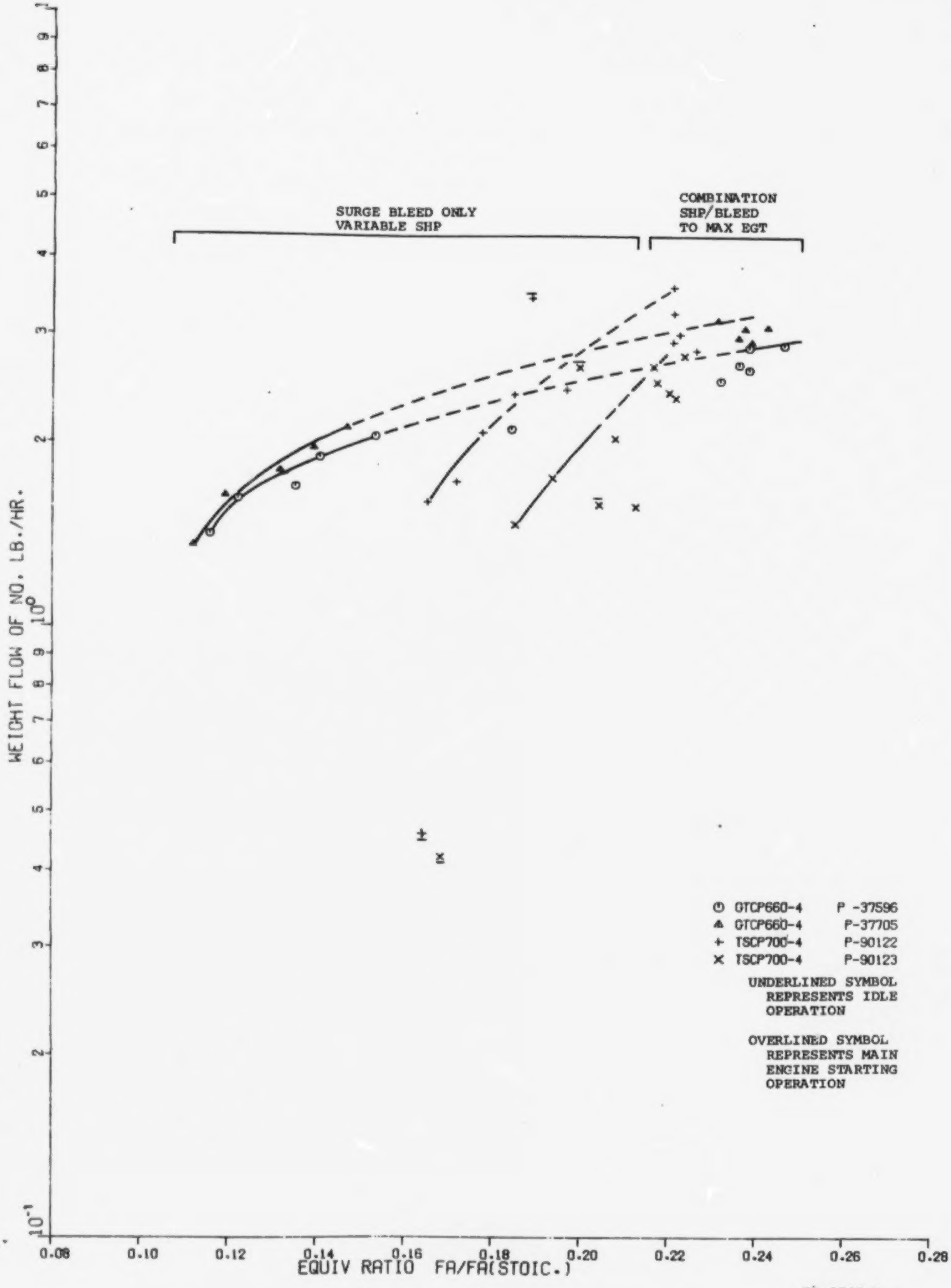

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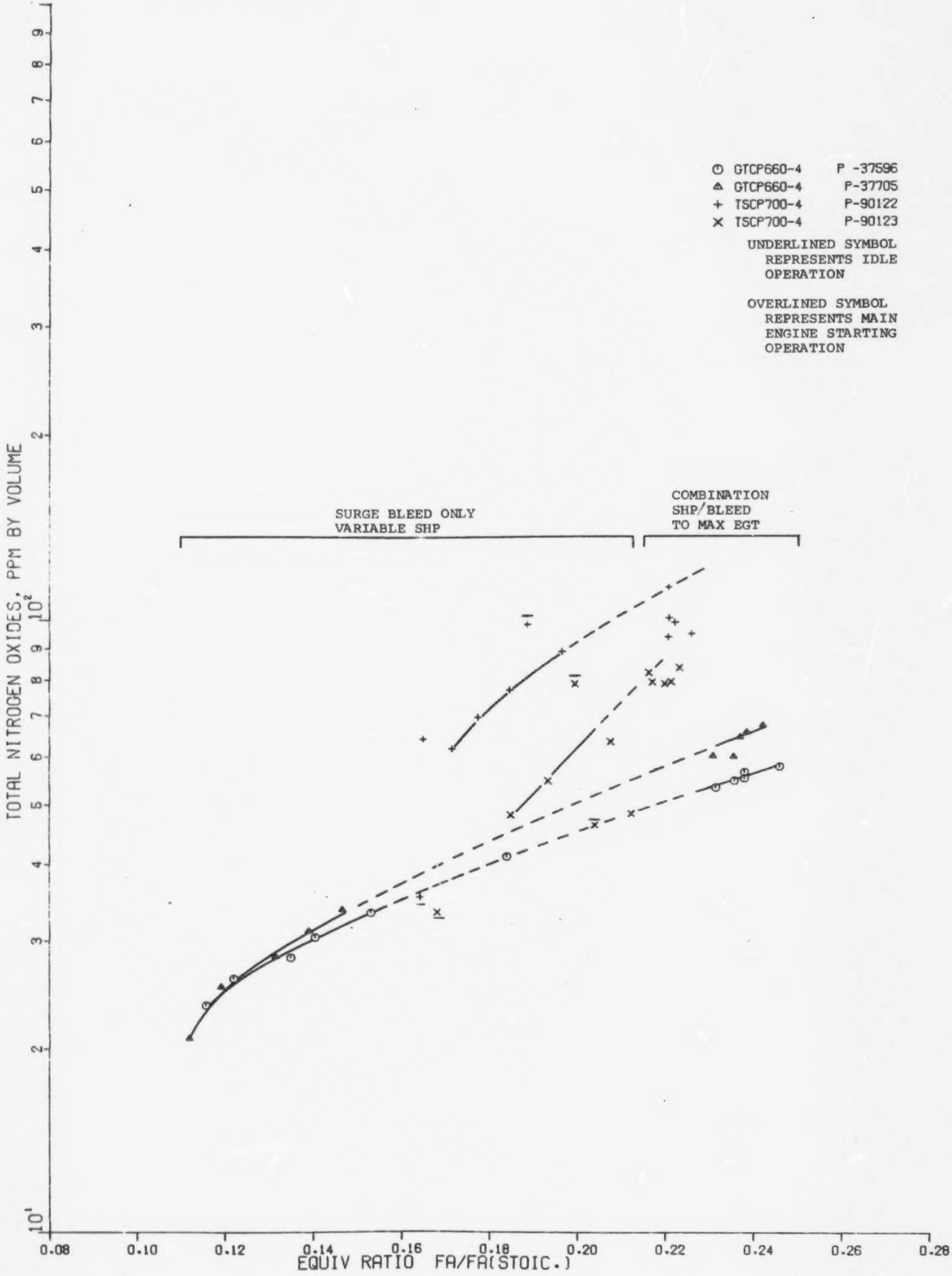

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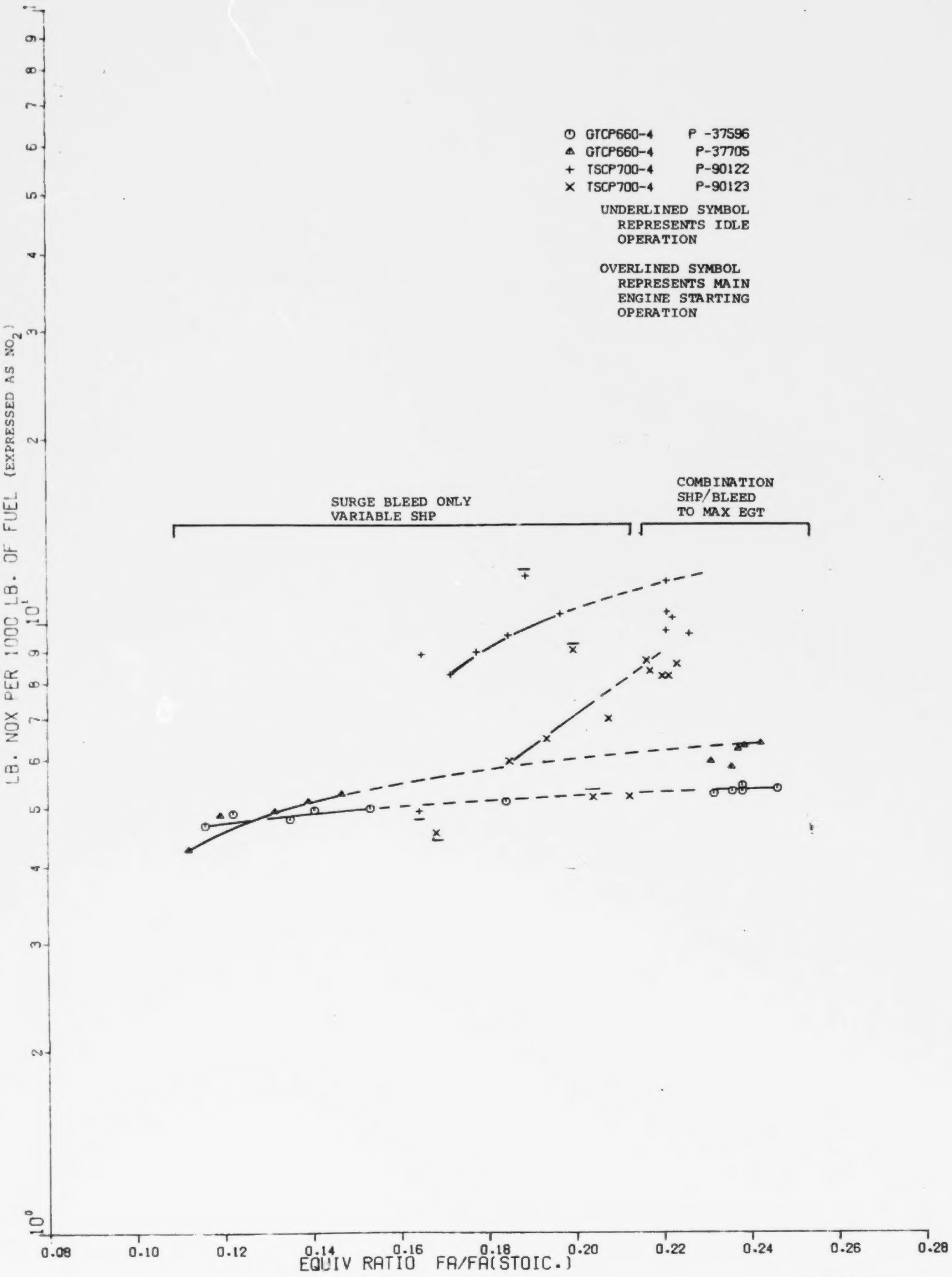

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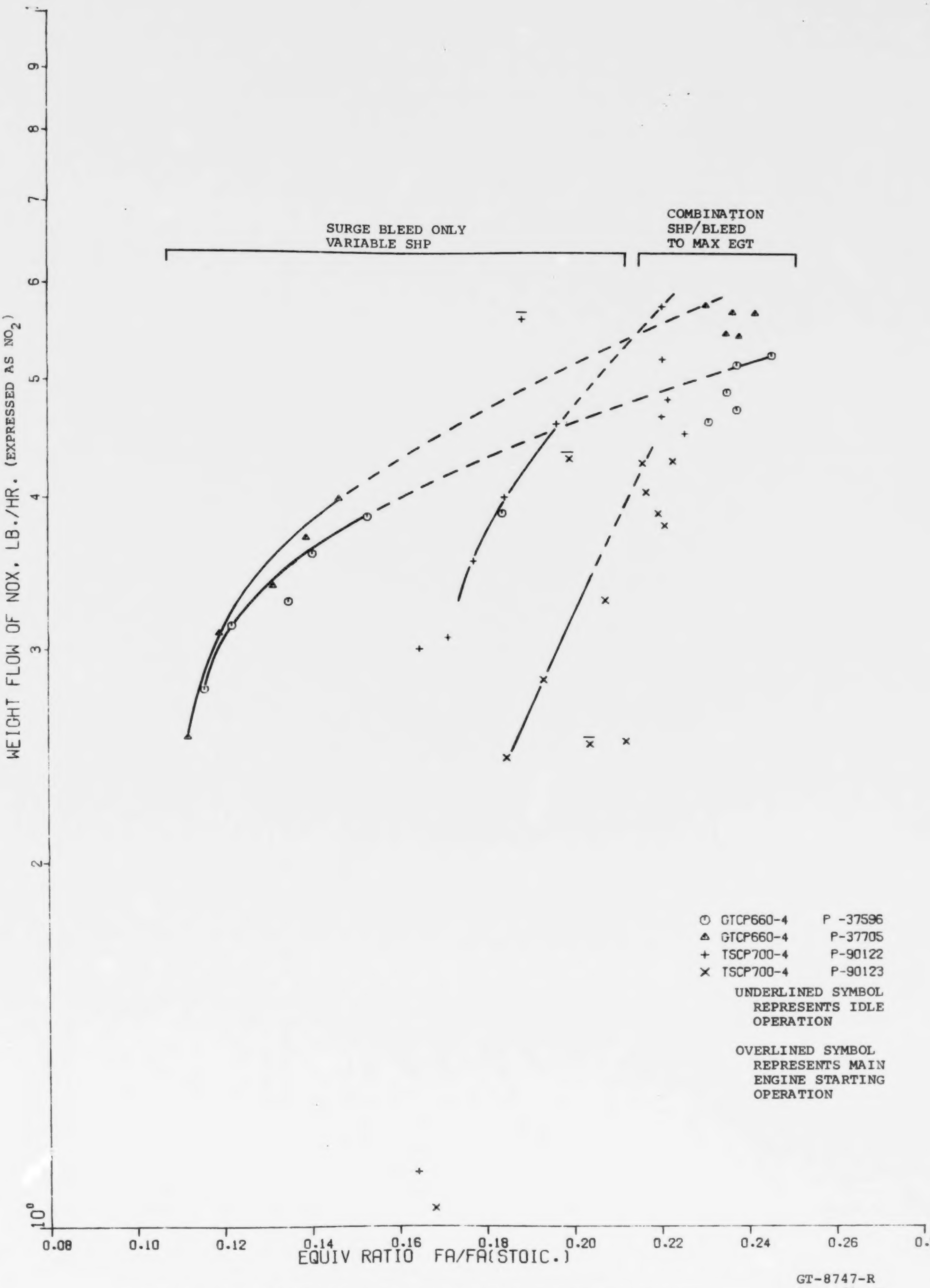

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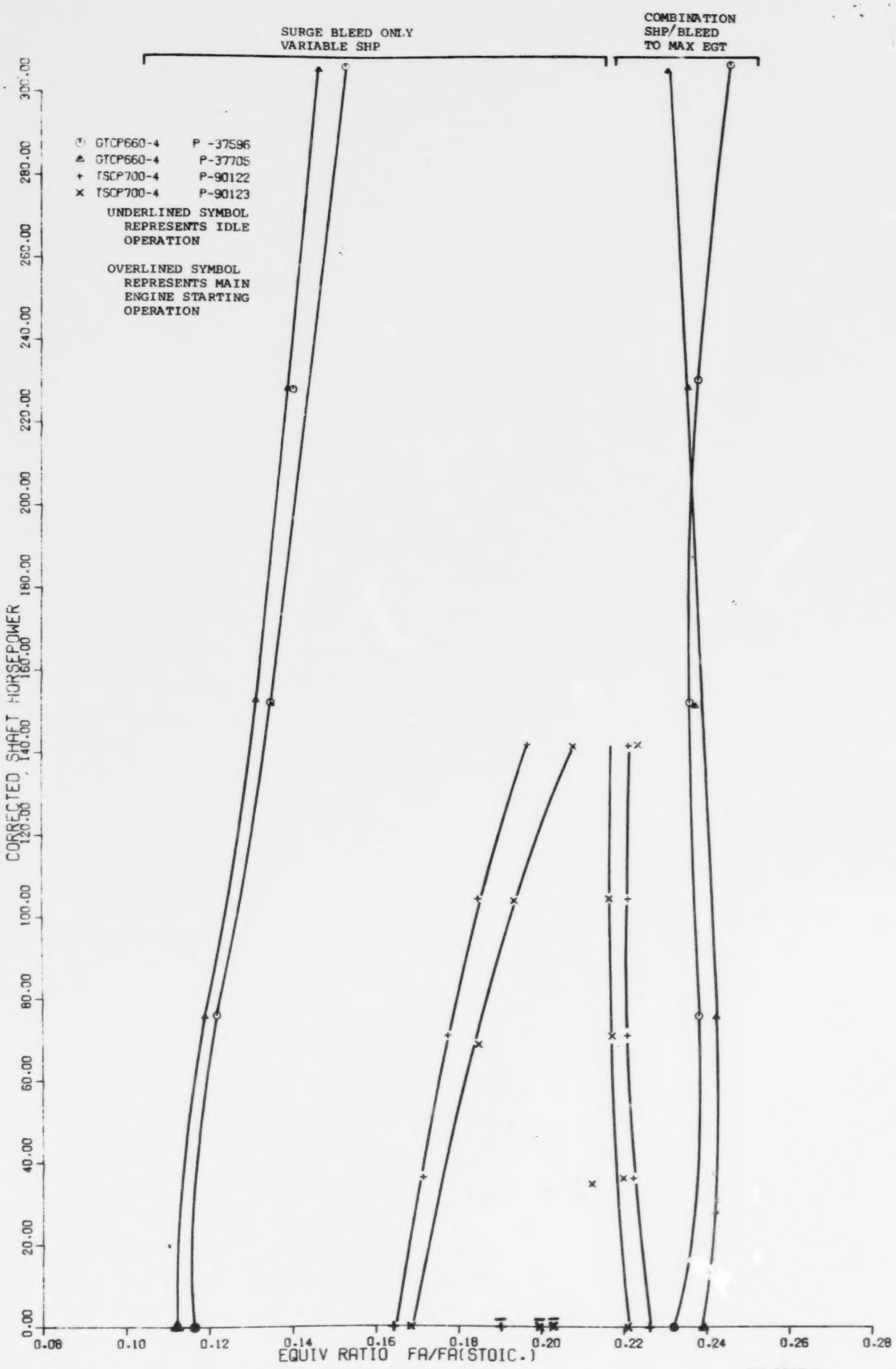

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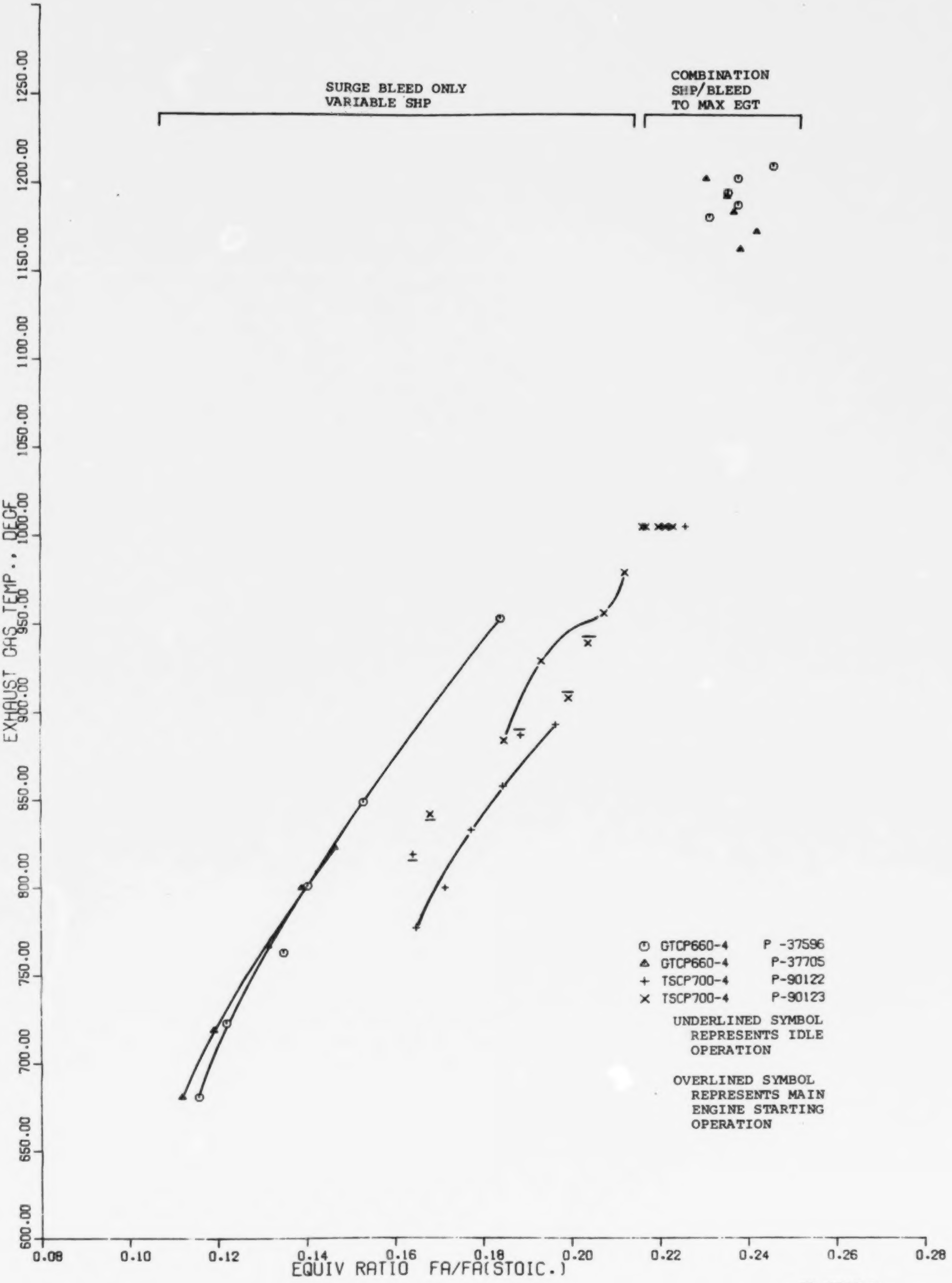

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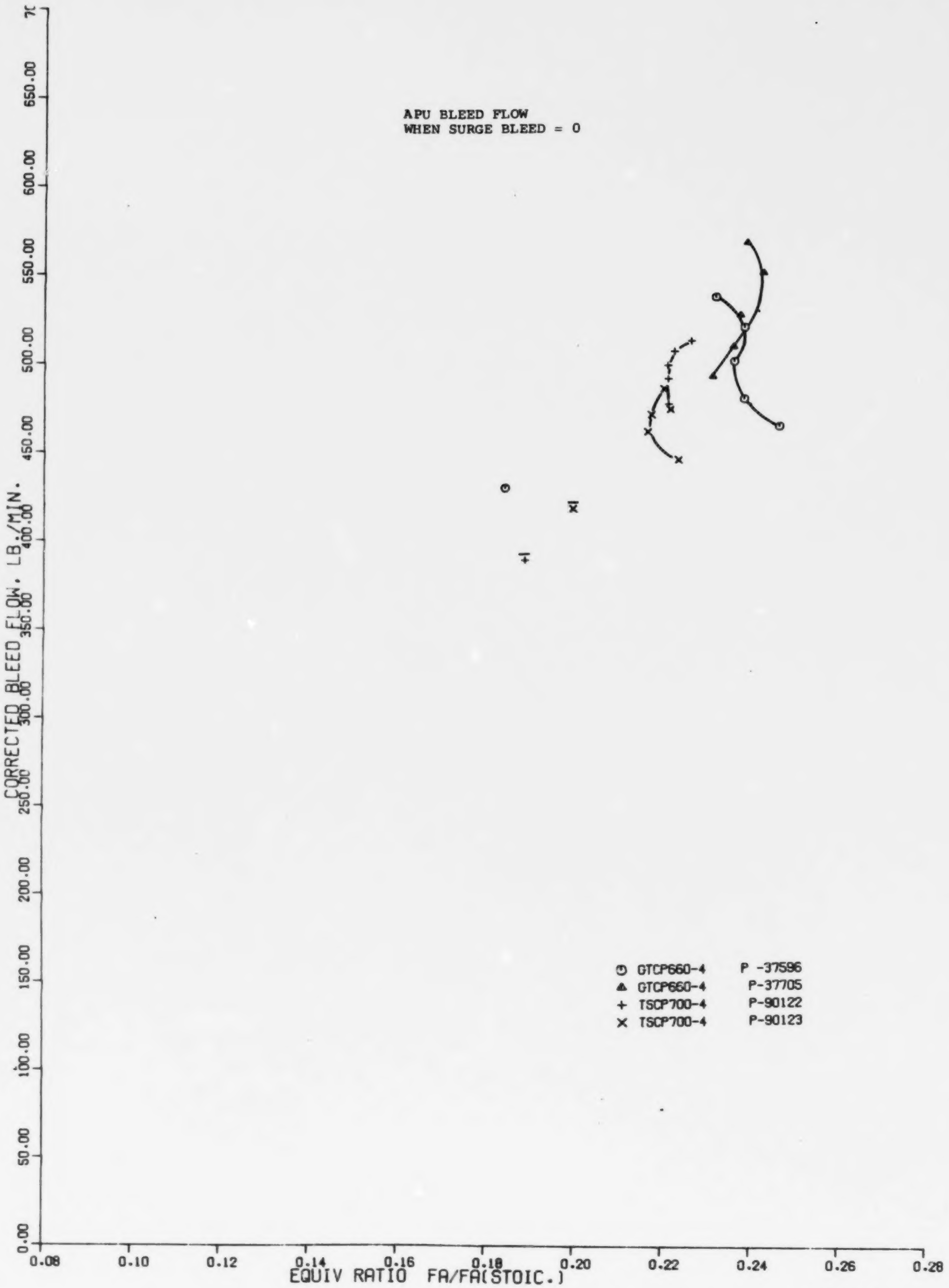

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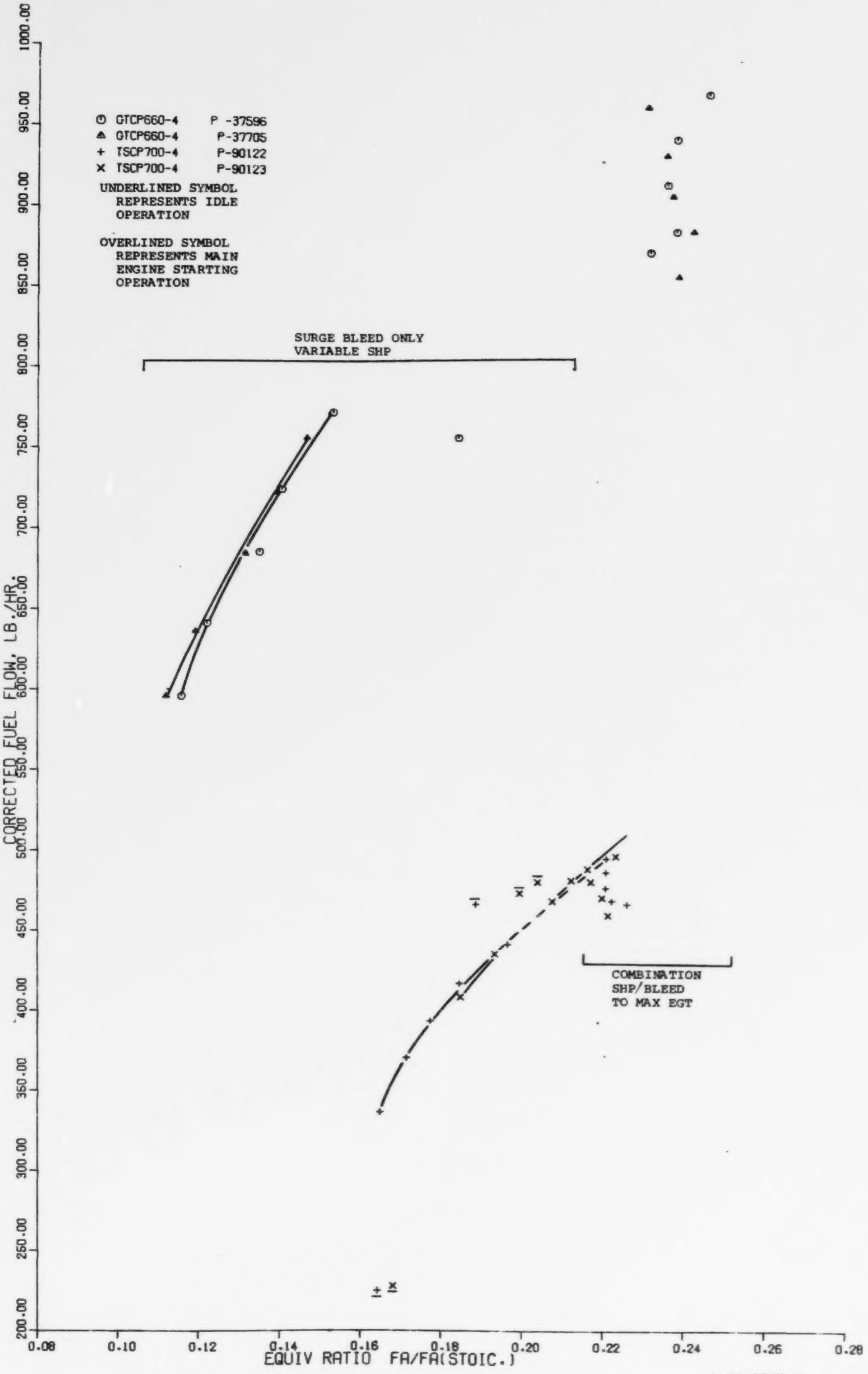


EPA / AIRESEARCH LARGE APU EXHAUST EMISSION SUMMARY

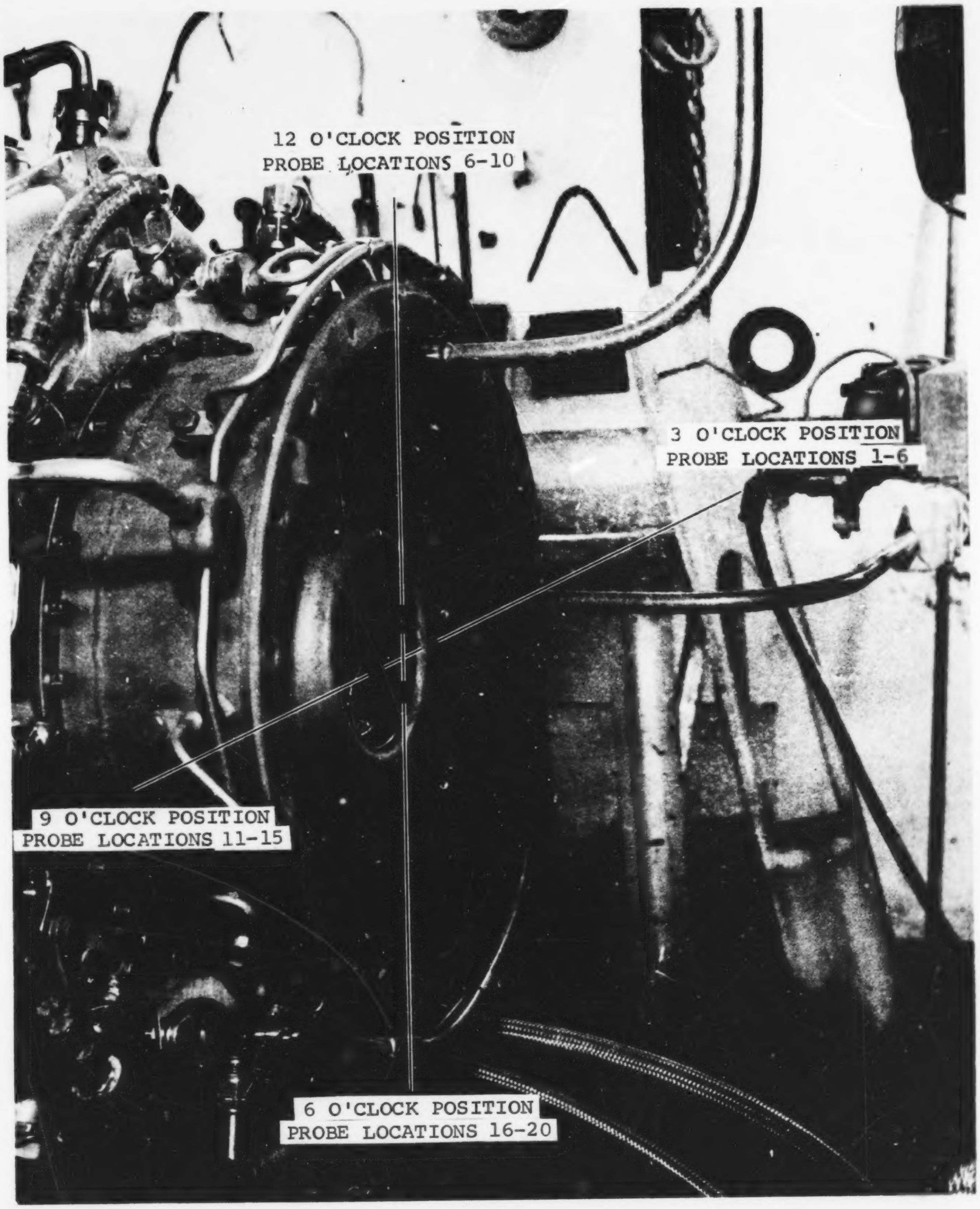
APPENDIX D

EXHAUST EMISSIONS STRATIFICATION CURVES

The emissions stratification curve index lists the engine model, serial number, and the corresponding page numbers on which curves of CO_2, CO, HC (HOT), NO and NO_x concentrations in ppm (except for CO_2 in mole. percent) are plotted as a function of sampling probe location in the exit plane of the exhaust duct for lines of constant power setting. Also, Figure 8 is included to show the probe number scheme and location. Note that the "TEST NO." shown on each curve means the same as power setting number as specified in Table 6 of this report.

CURVE INDEX

ENGINE MODEL	S/N	APPENDIX D
Group 1 Propulsion Engines		Page Numbers
TFE731-2	7305-2	1 through 5
TSE231-1	2301-10	6 through 10
TPE331-1-151G	P-91165	11 through 15
TPE331-1-151G	P-91168	16 through 20
TPE331-43A	P-61157	21 through 25
T76-G-410	GE00790	26 through 30
Group 2 (Small APUs)		Page Numbers
GTCP30-92	P-28794	31 through 35
GTCP30-92	P-28794	36 through 40
GTCP36-6	P-34696	41 through 45
GTCP36-6	P-34772	46 through 50
Group 3 (Medium APUs)		Page Numbers
GTCP85-180	P-567	51 through 55
GTCP85-180	P-507	56 through 60
GTCP85-180	P-518	61 through 65
GTCP85-180	P-595	66 through 70
GTCP85-180	P-593	71 through 75
GTCP85-98CK	P-35648	76 through 80
GTCP85-98D	P-27692	81 through 85
GTCP85-98D	P-27857	86 through 90
GTCP85-98	P-15454	91 through 95
GTCP85-98	P-15257	96 through 100
GTCP85-98	P-15541	101 through 105
GTCP85-115	P-18725	106 through 110
GTCP85-115	P-18781	111 through 115
GTCP85-115	P-18702	116 through 120
GTCP85-129	P-34763	121 through 125
GTC85-90	P-5786	126 through 130
GTC85-90B	P-24504	131 through 135
GTC85-90B	P-34276	136 through 140
Group 4 (Large APUs)		Page Numbers
GTCP660-4	P-37596	141 through 145
GTCP660-4	P-37705	146 through 150
TSCP700-4	P-90122	151 through 155
TSCP700-4	P-90123	156 through 160


12 O'CLOCK POSITION
PROBE LOCATIONS 6-10
3 O'CLOCK POSITION
PROBE LOCATIONS 1-6
9 O'CLOCK POSITION
PROBE LOCATIONS 11-15
6 O'CLOCK POSITION
PROBE LOCATIONS 16-20

MP 30231

MOVABLE PROBE LOCATIONS AS ASSIGNED TO A
RADIAL CLOCK POSITION ILLUSTRATED ON A TPE331
ENGINE TEST SETUP

FIGURE 8

GROUP 1

AIRCRAFT PROPULSION ENGINES

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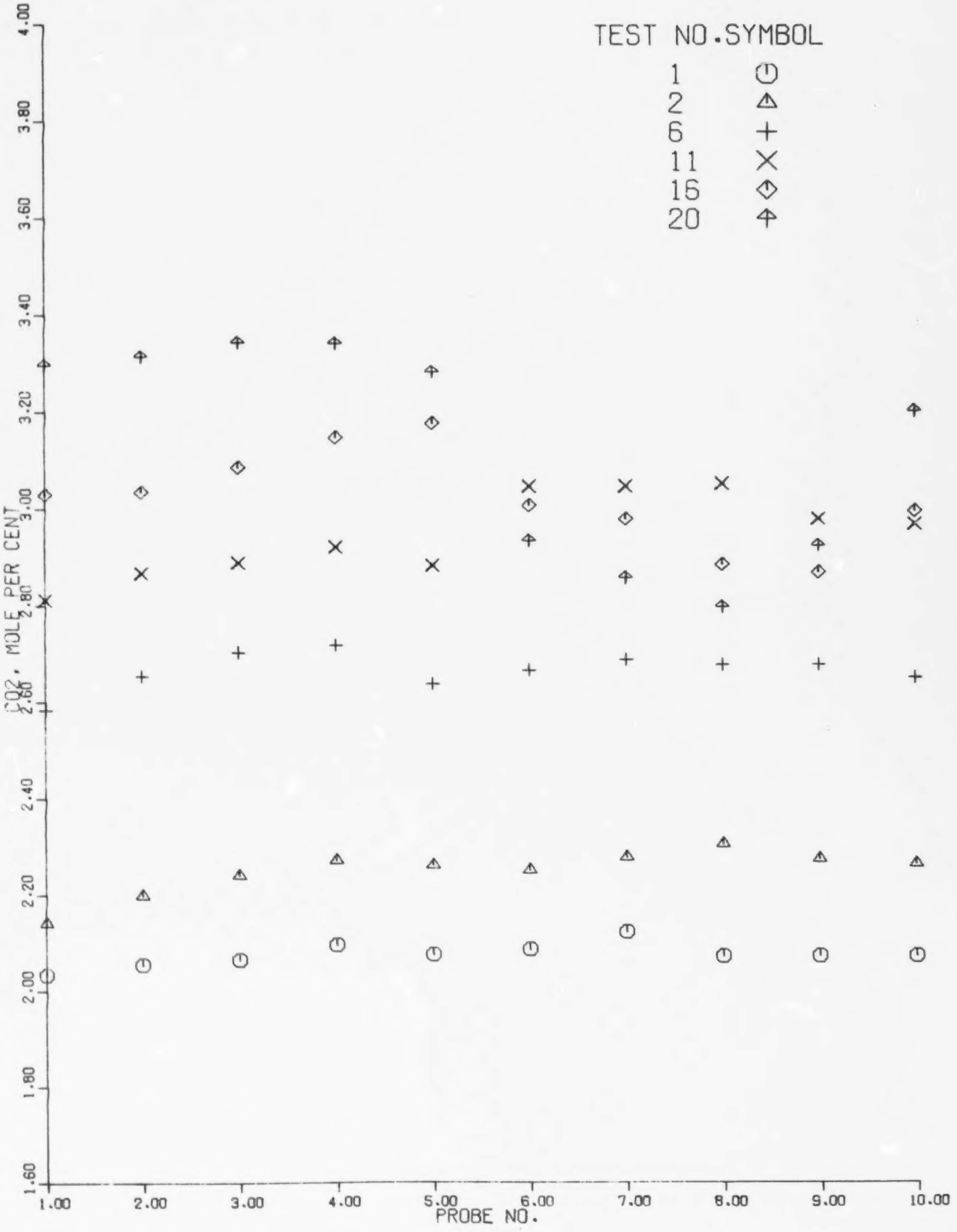

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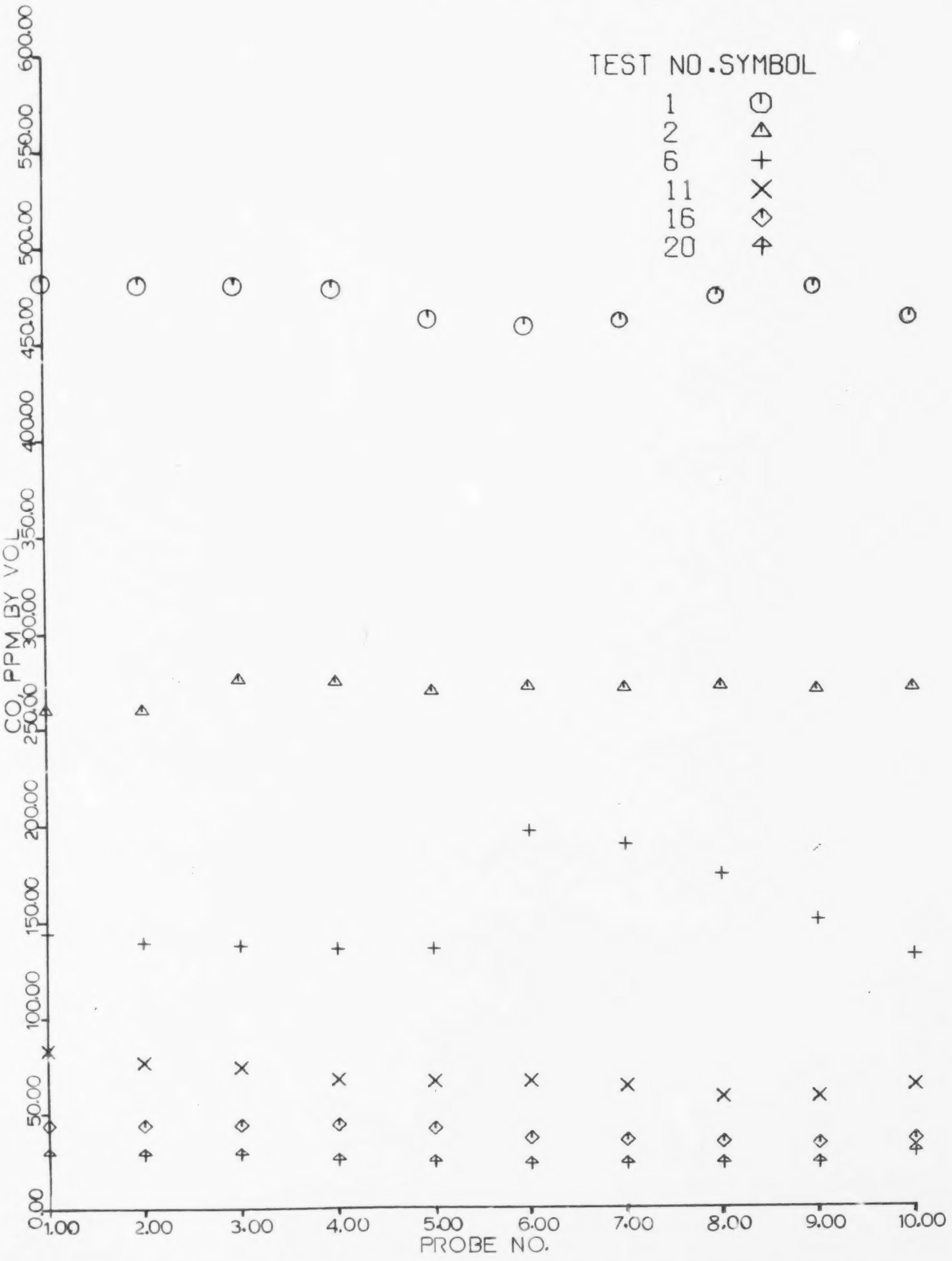
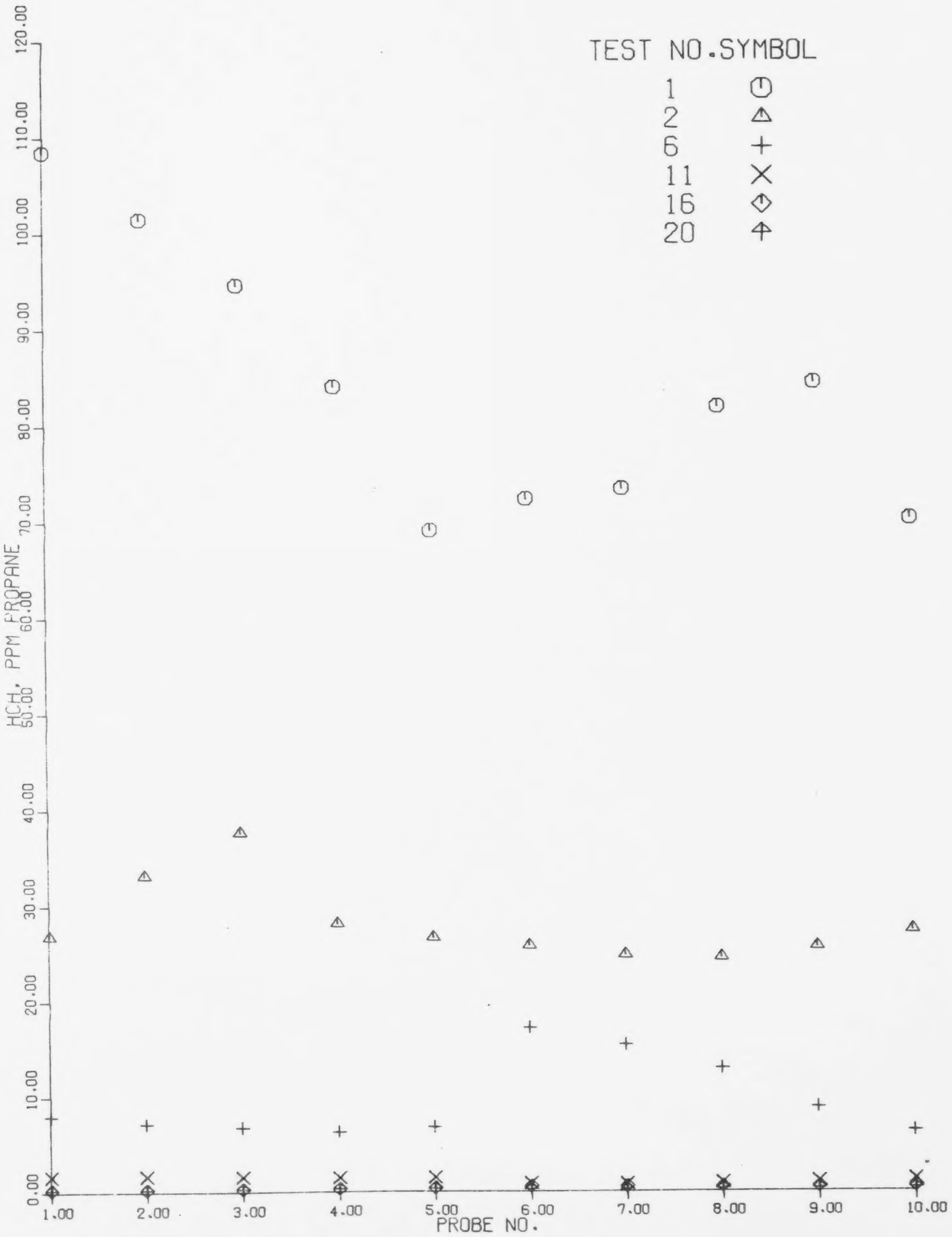


TFE 731-2 S/N 7305-2 DEV. FUEL AV.KEROS. DATE 6/10/71 CELL DENG



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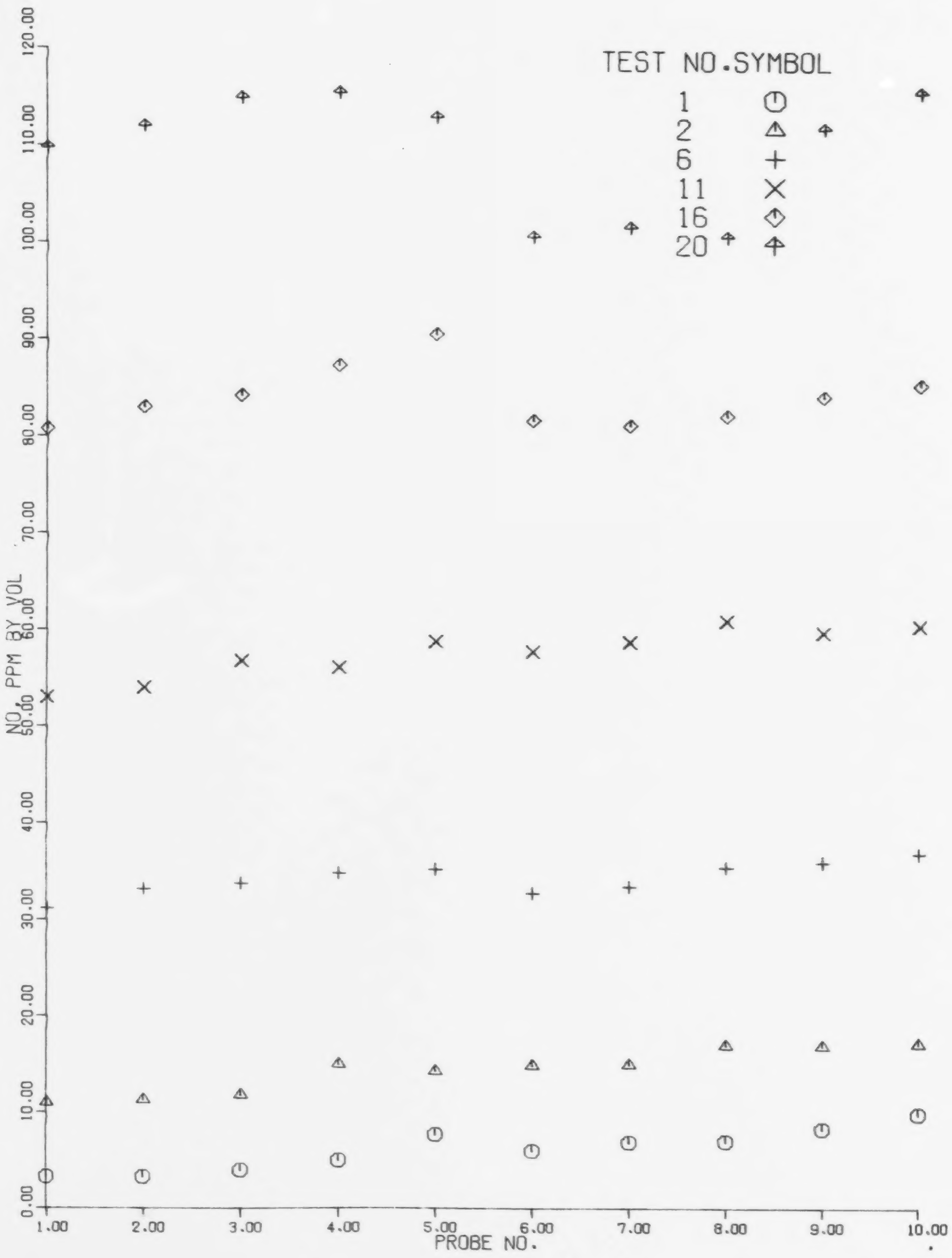

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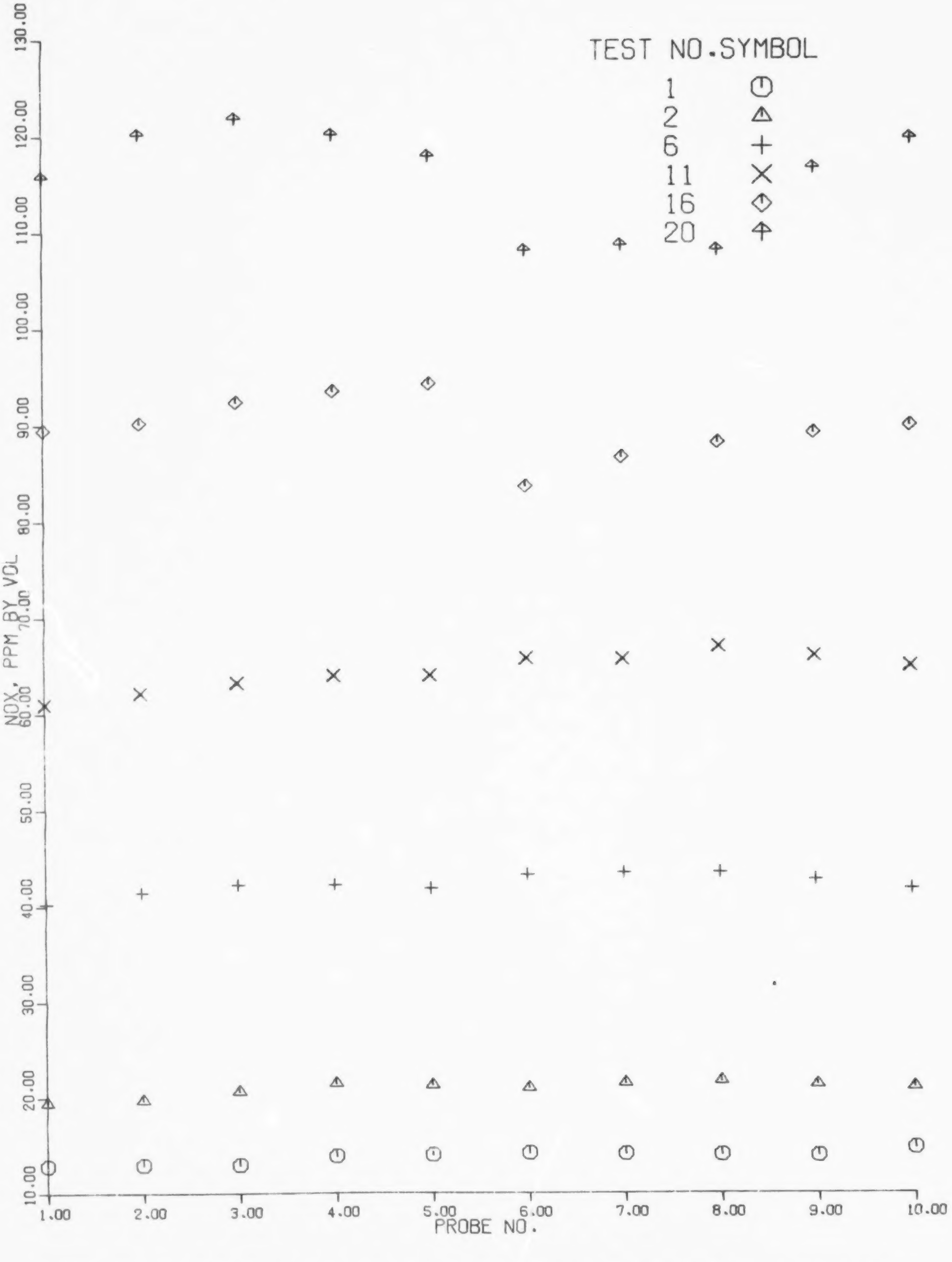

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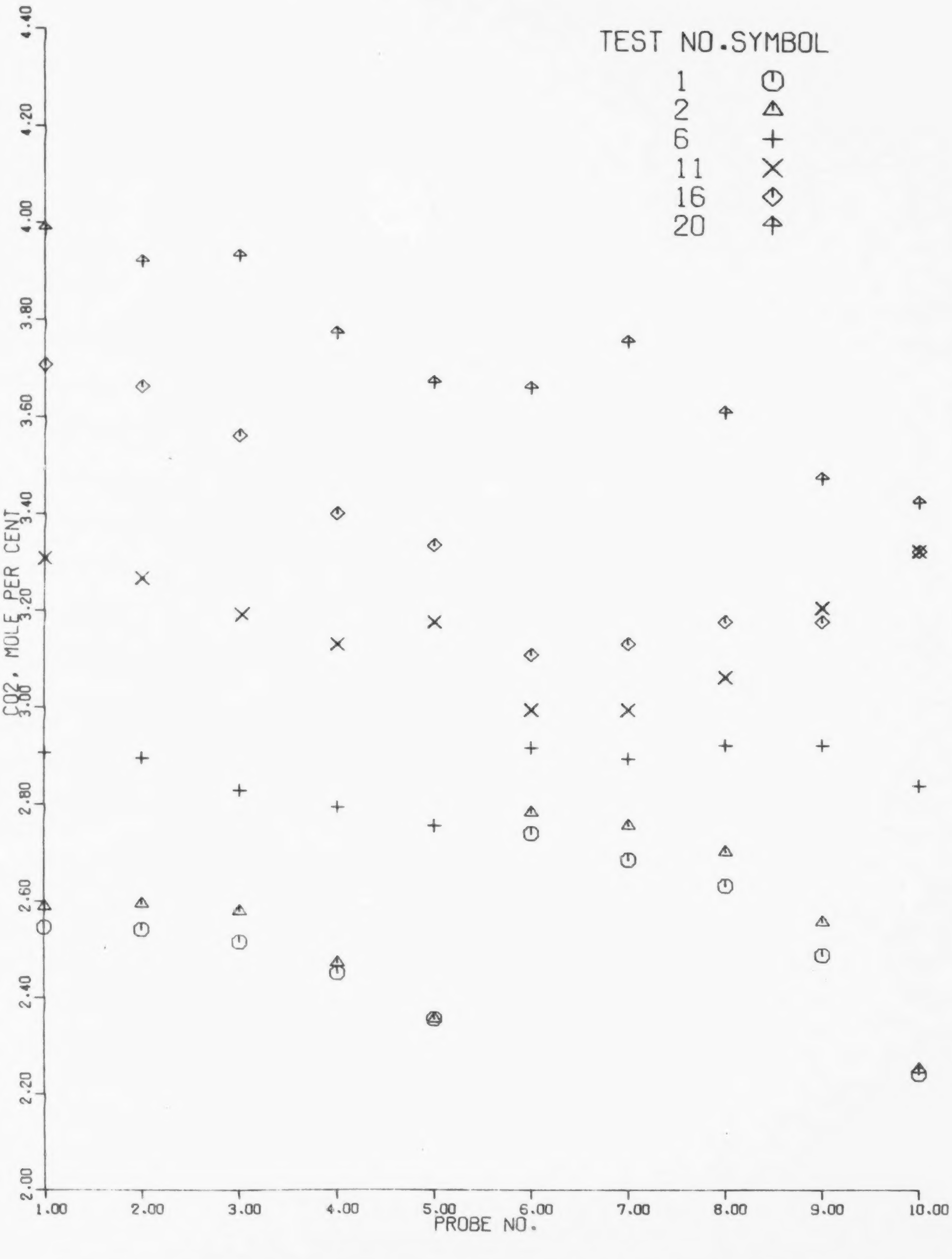

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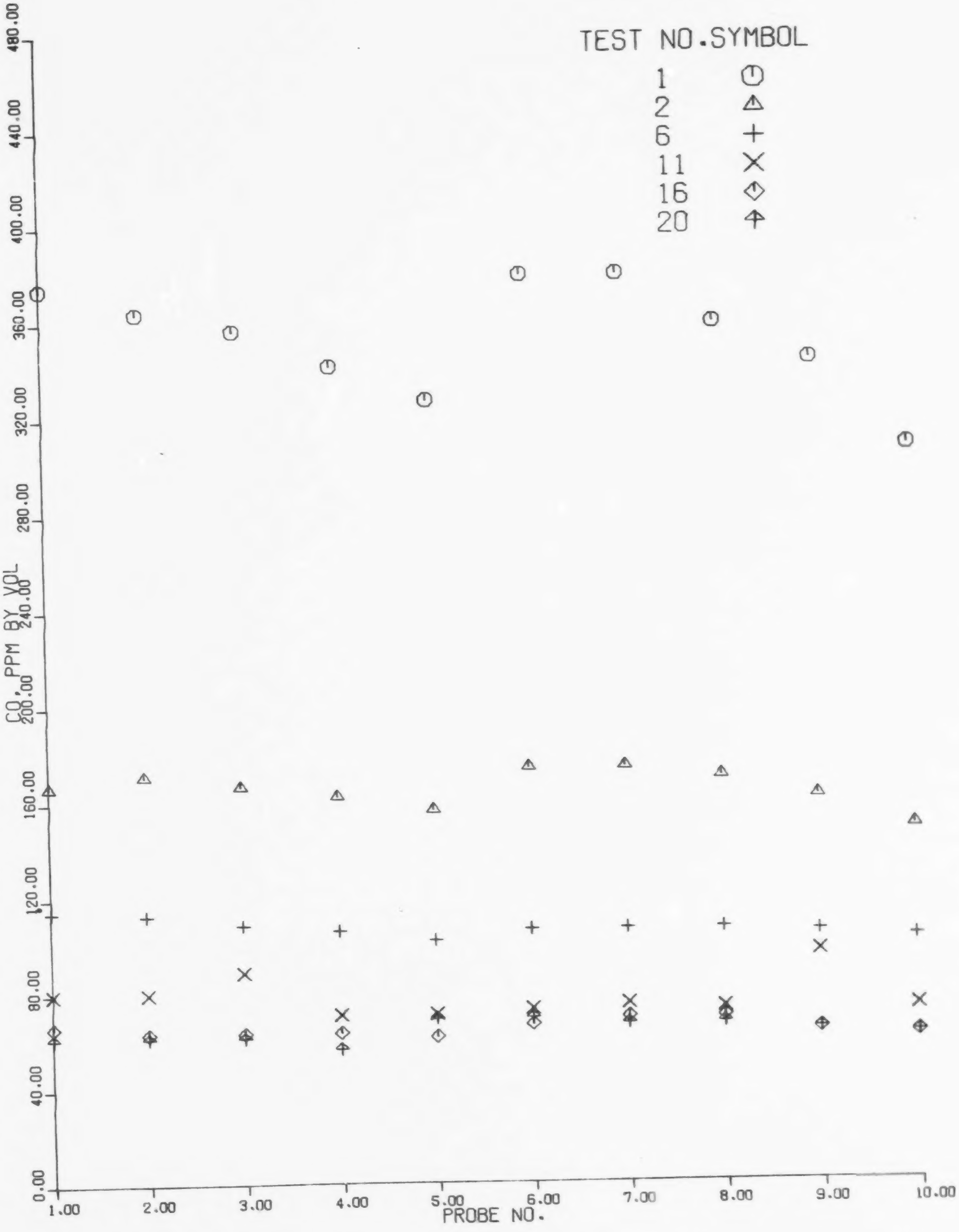

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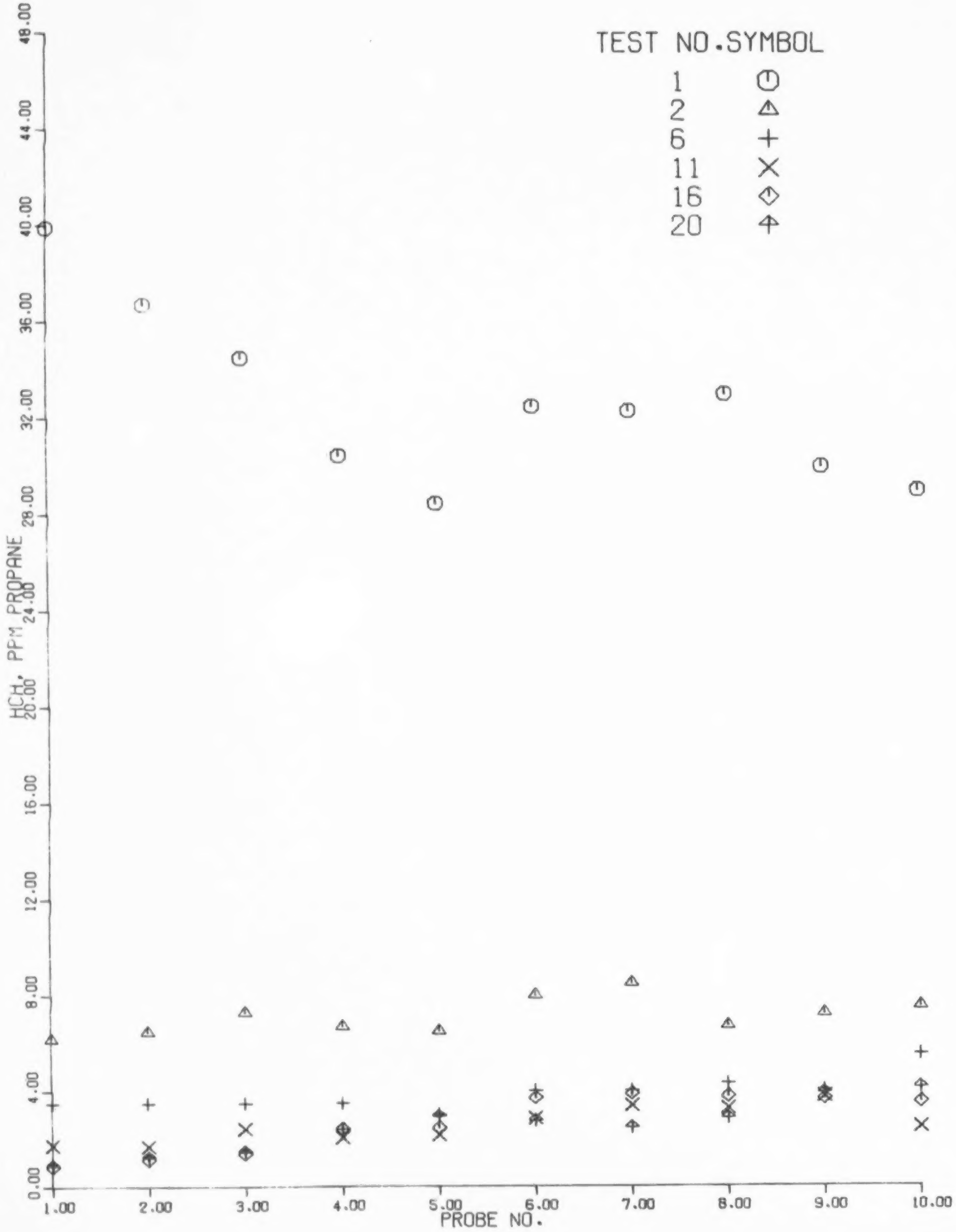

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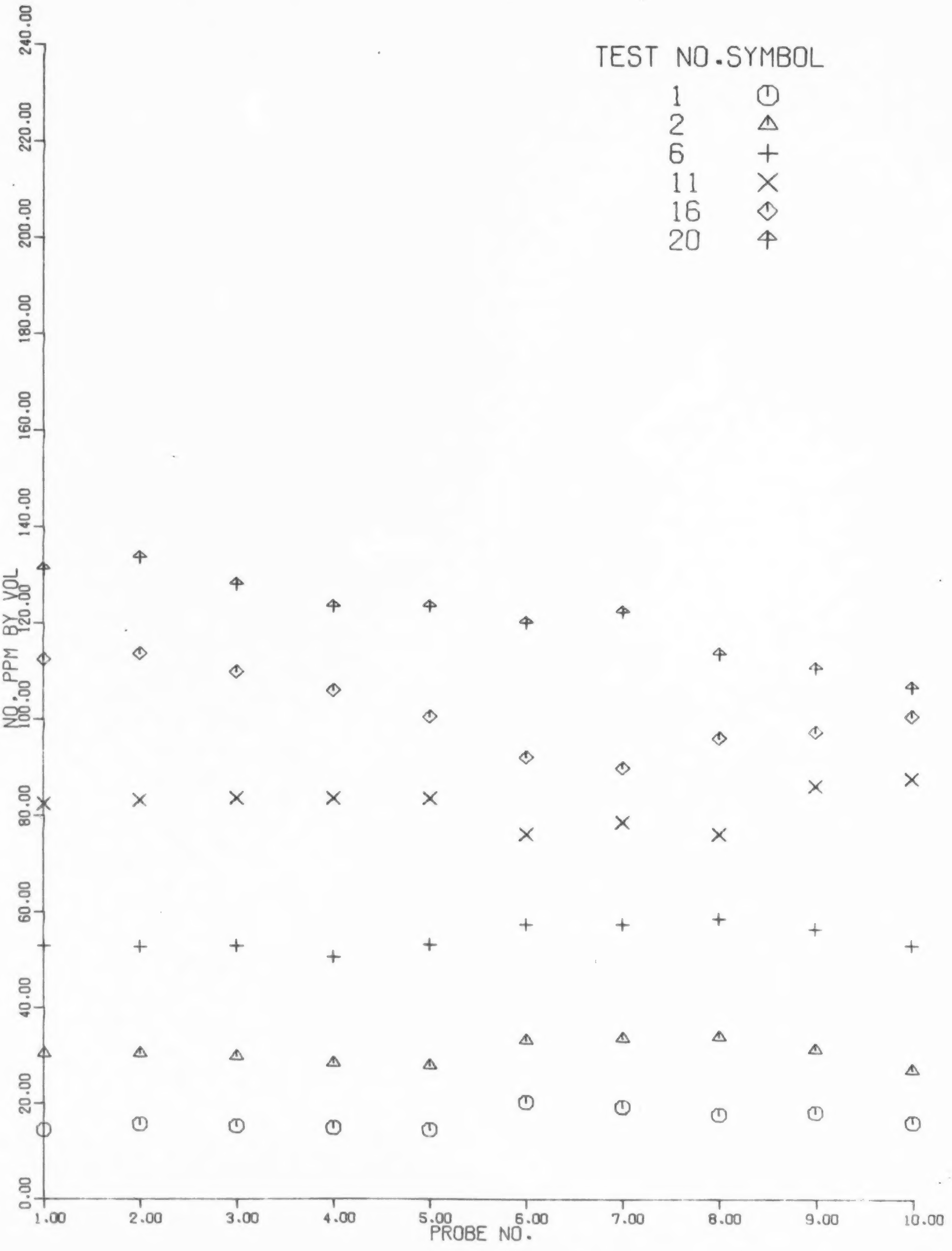

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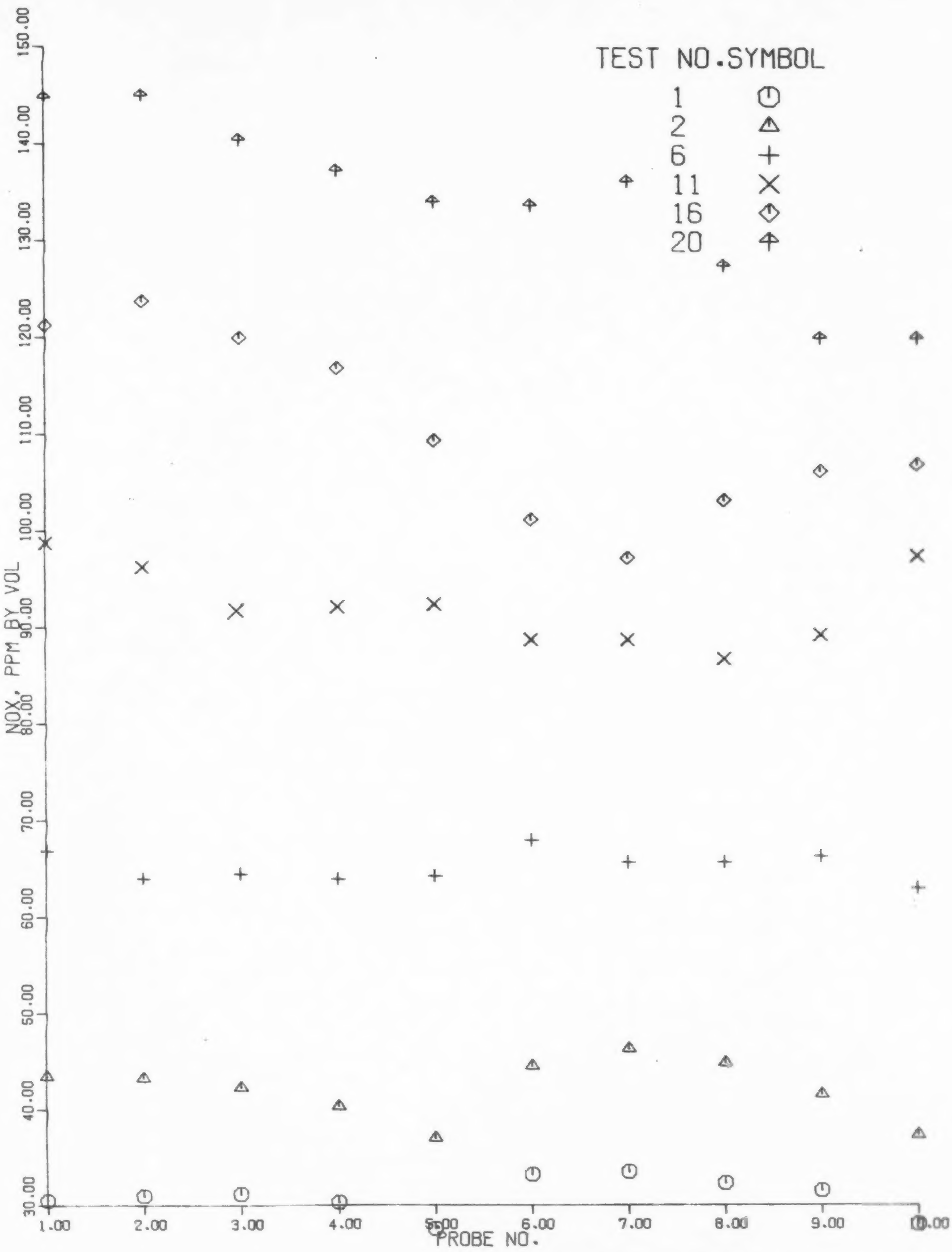

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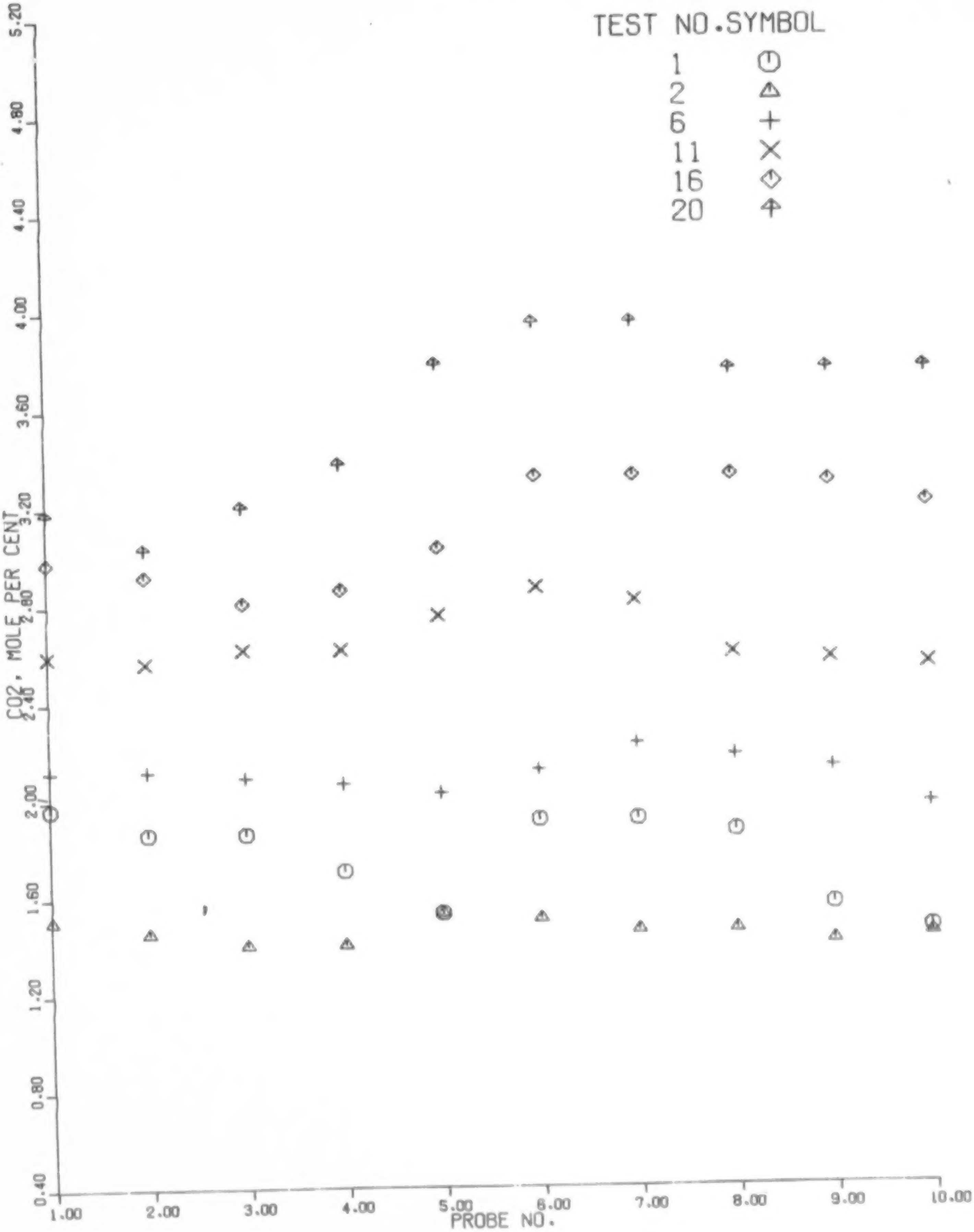

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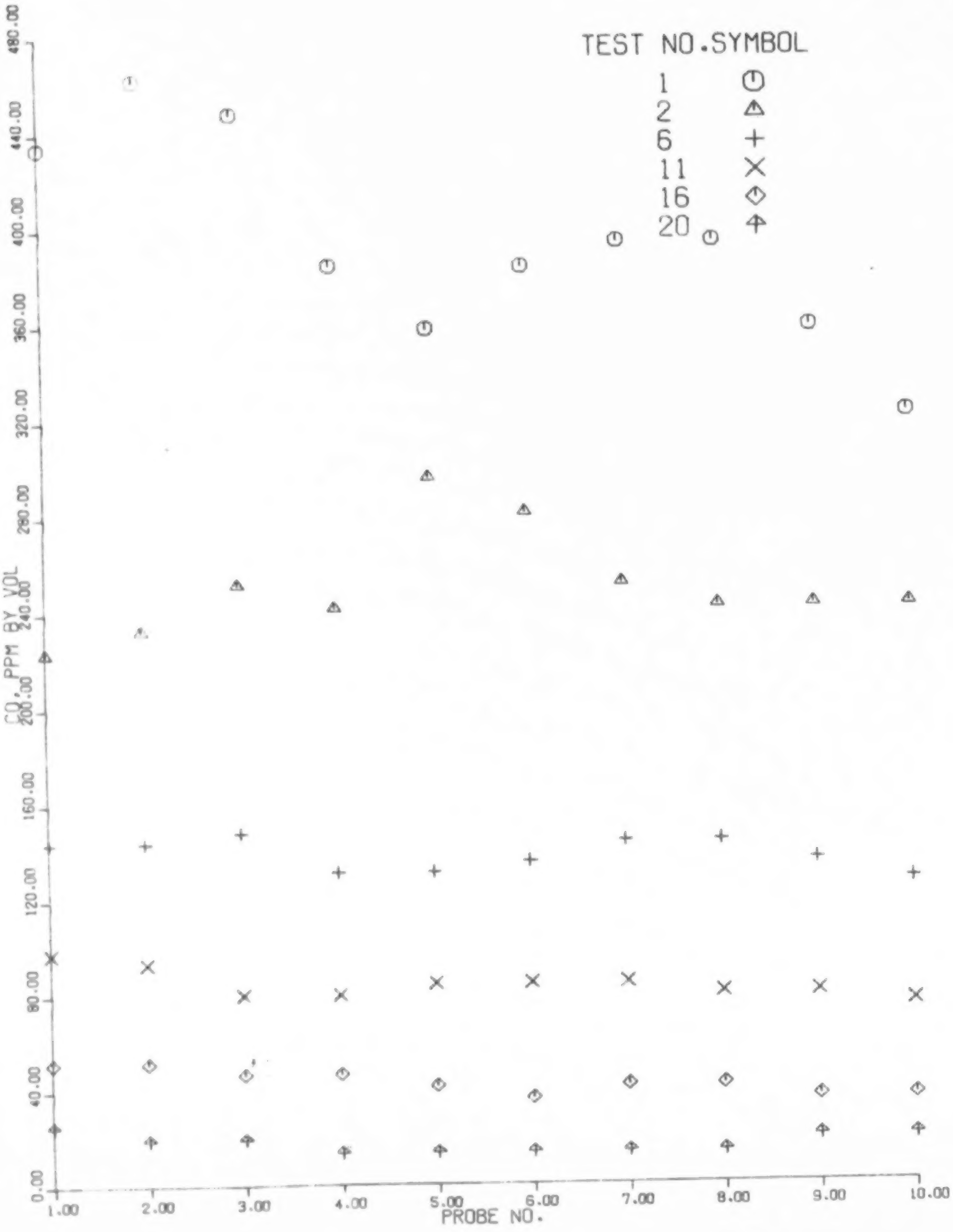

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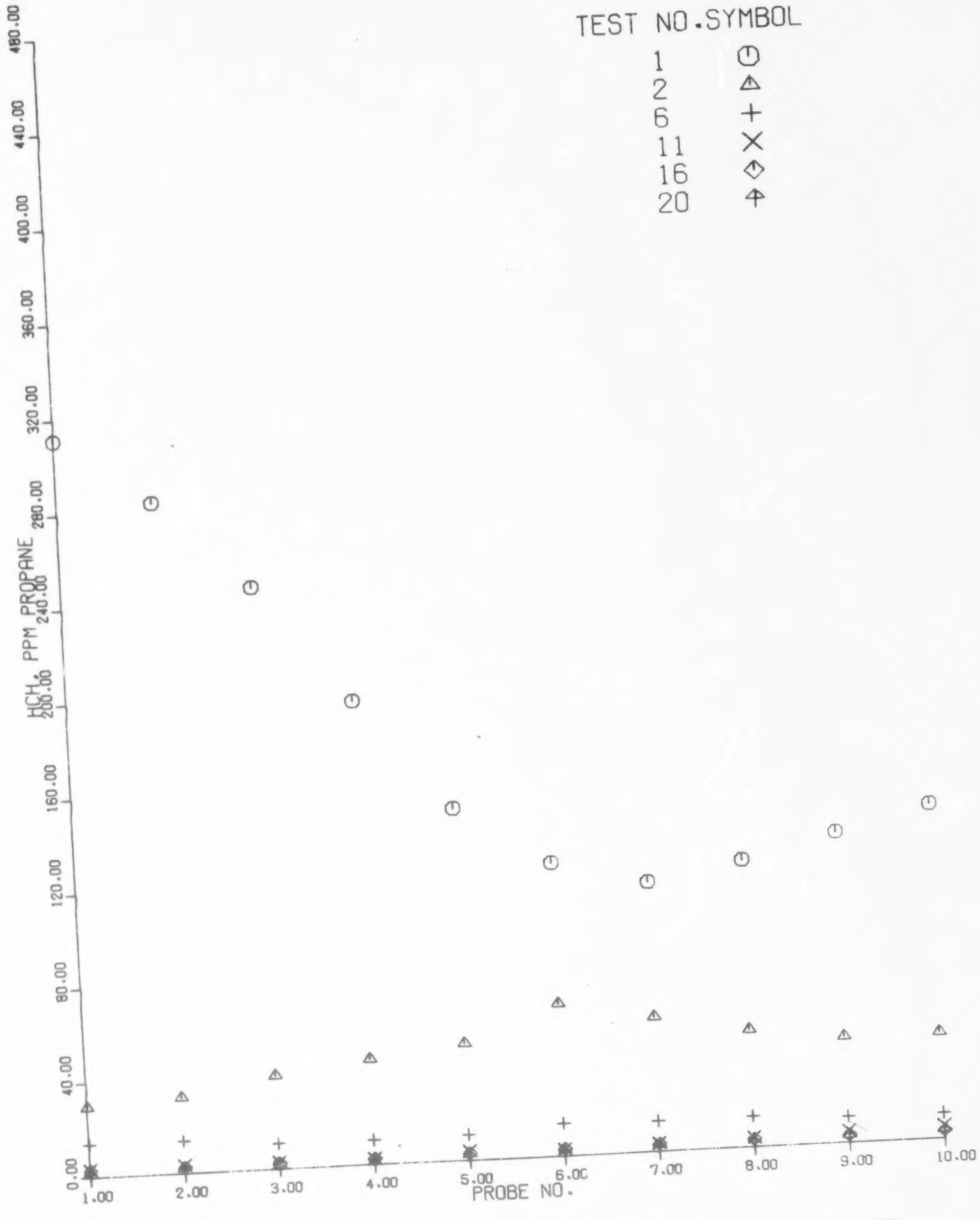

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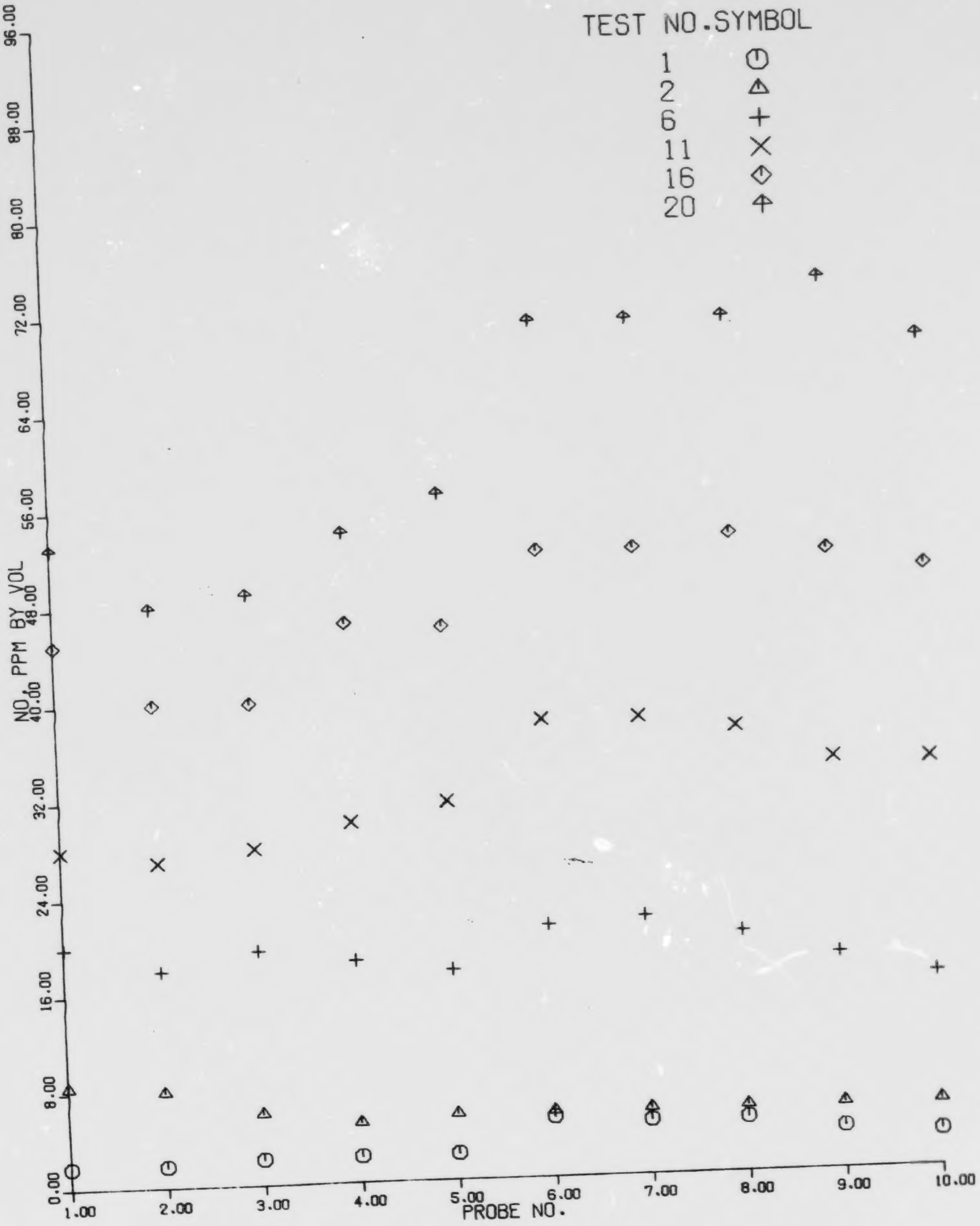

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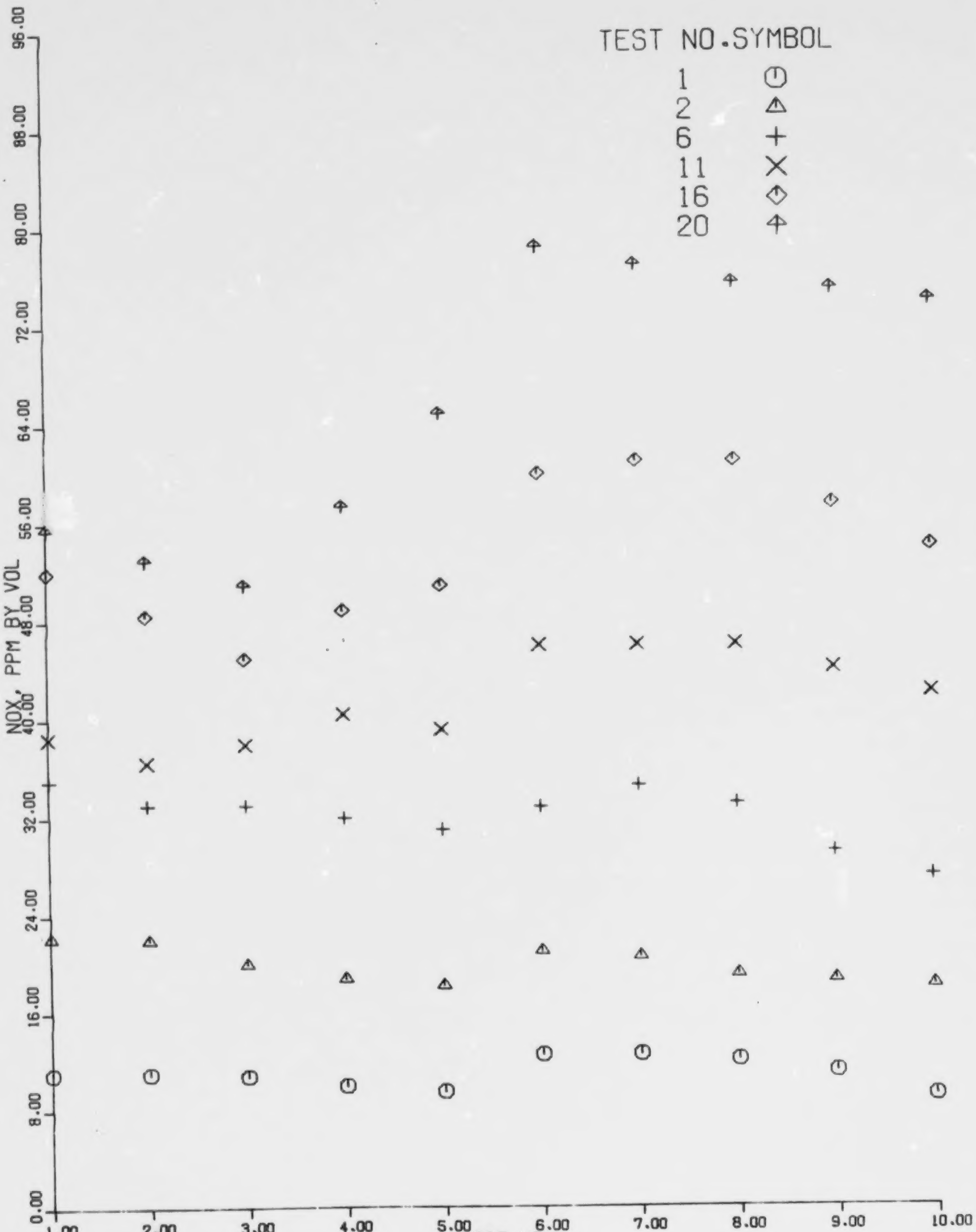

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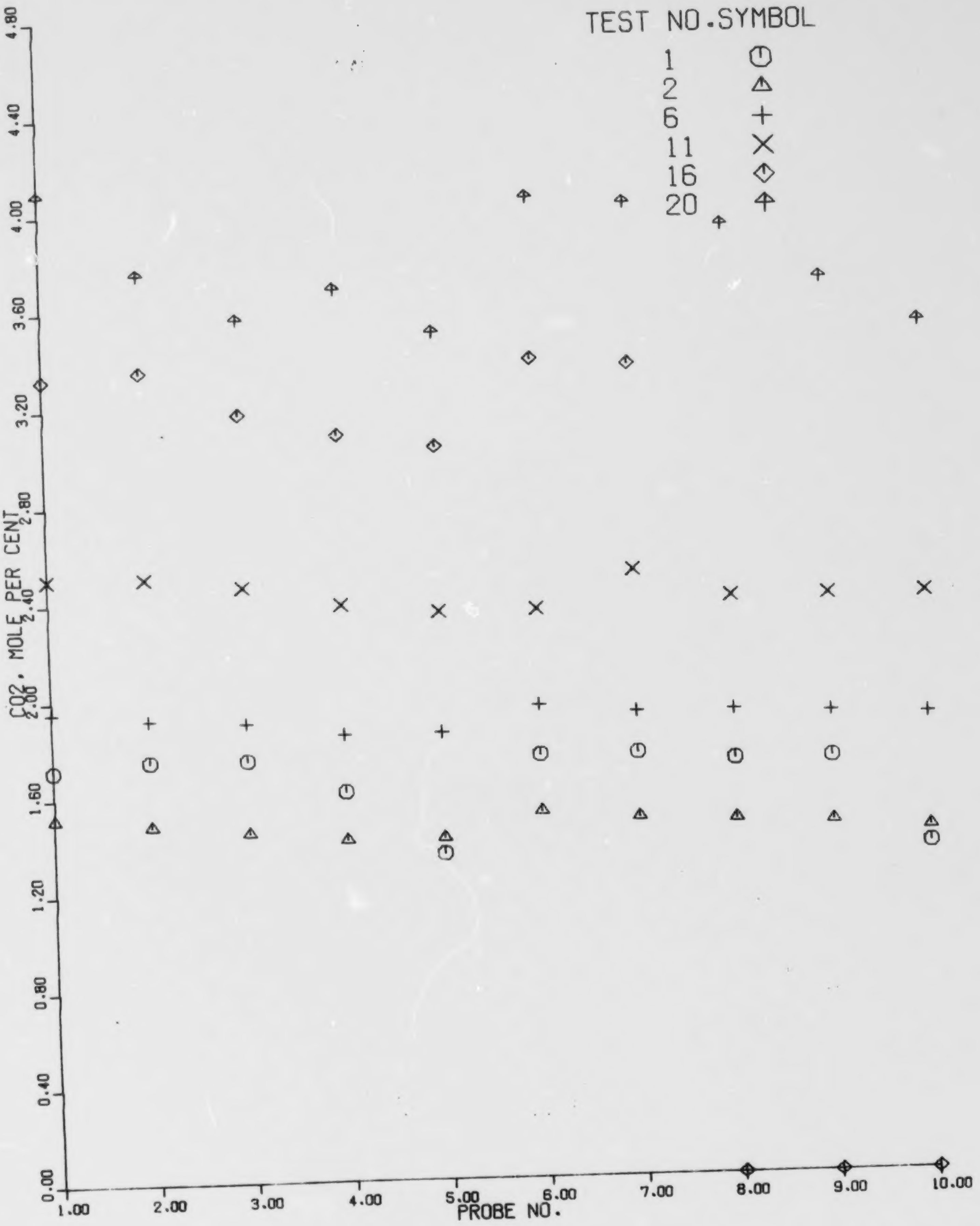

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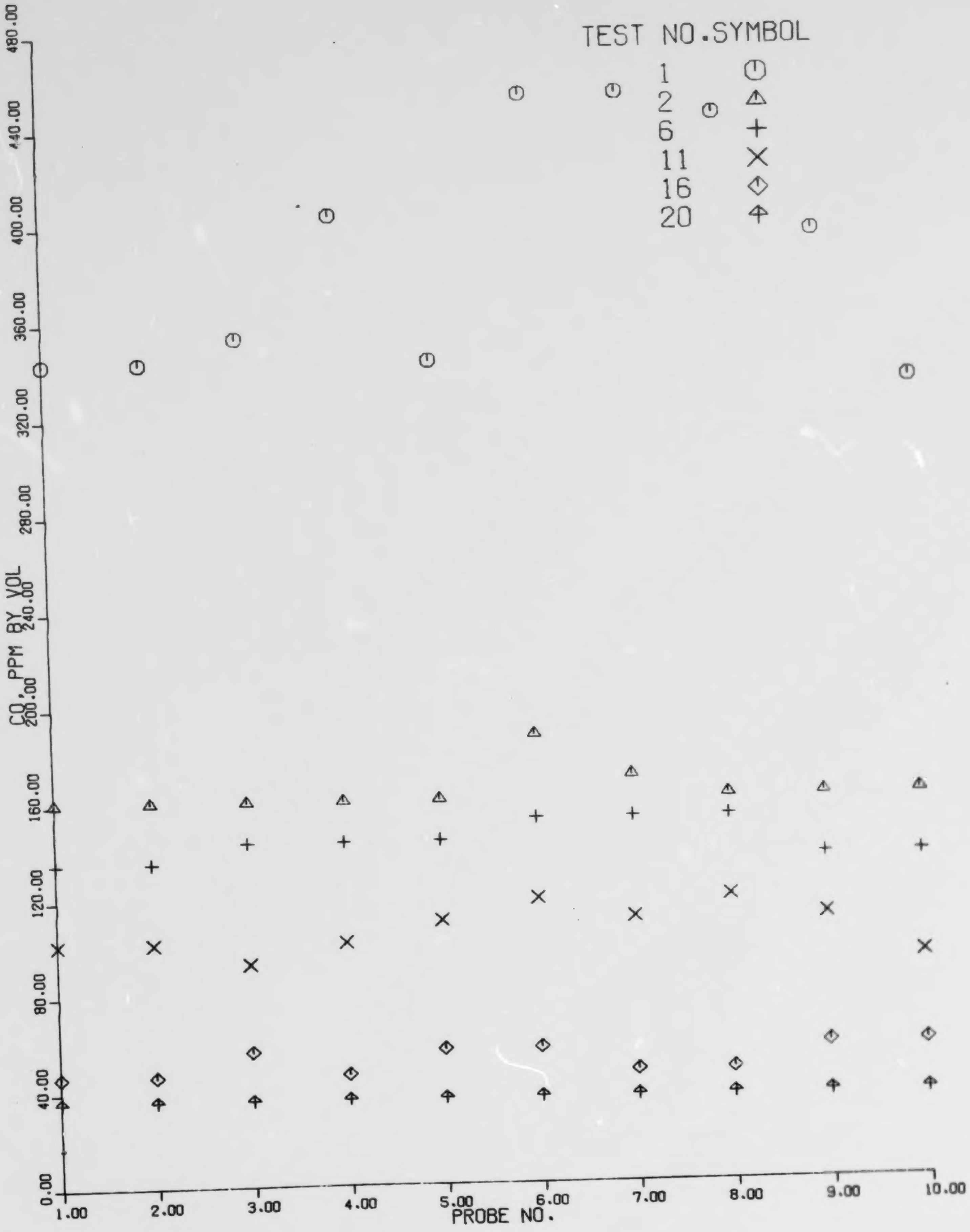

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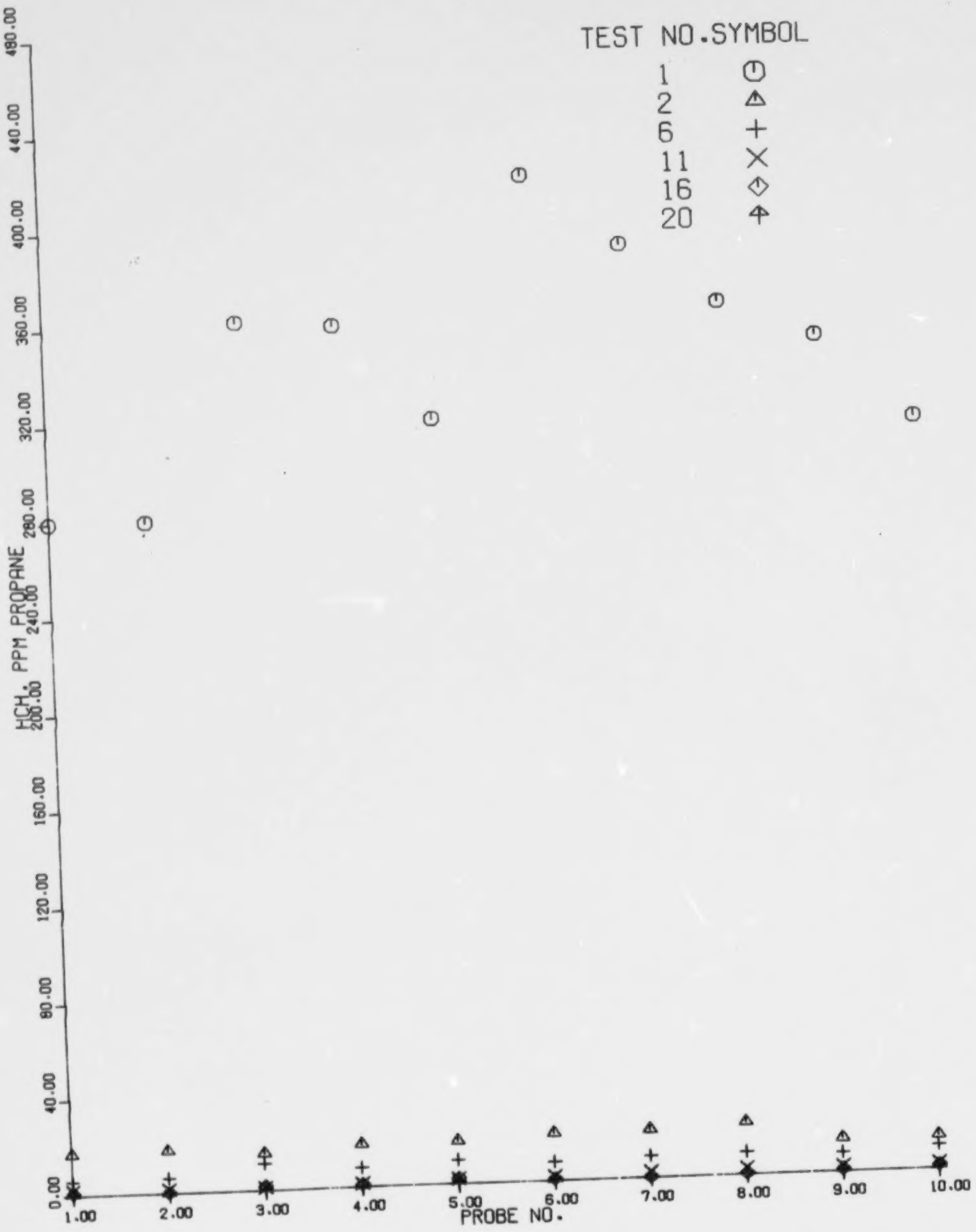

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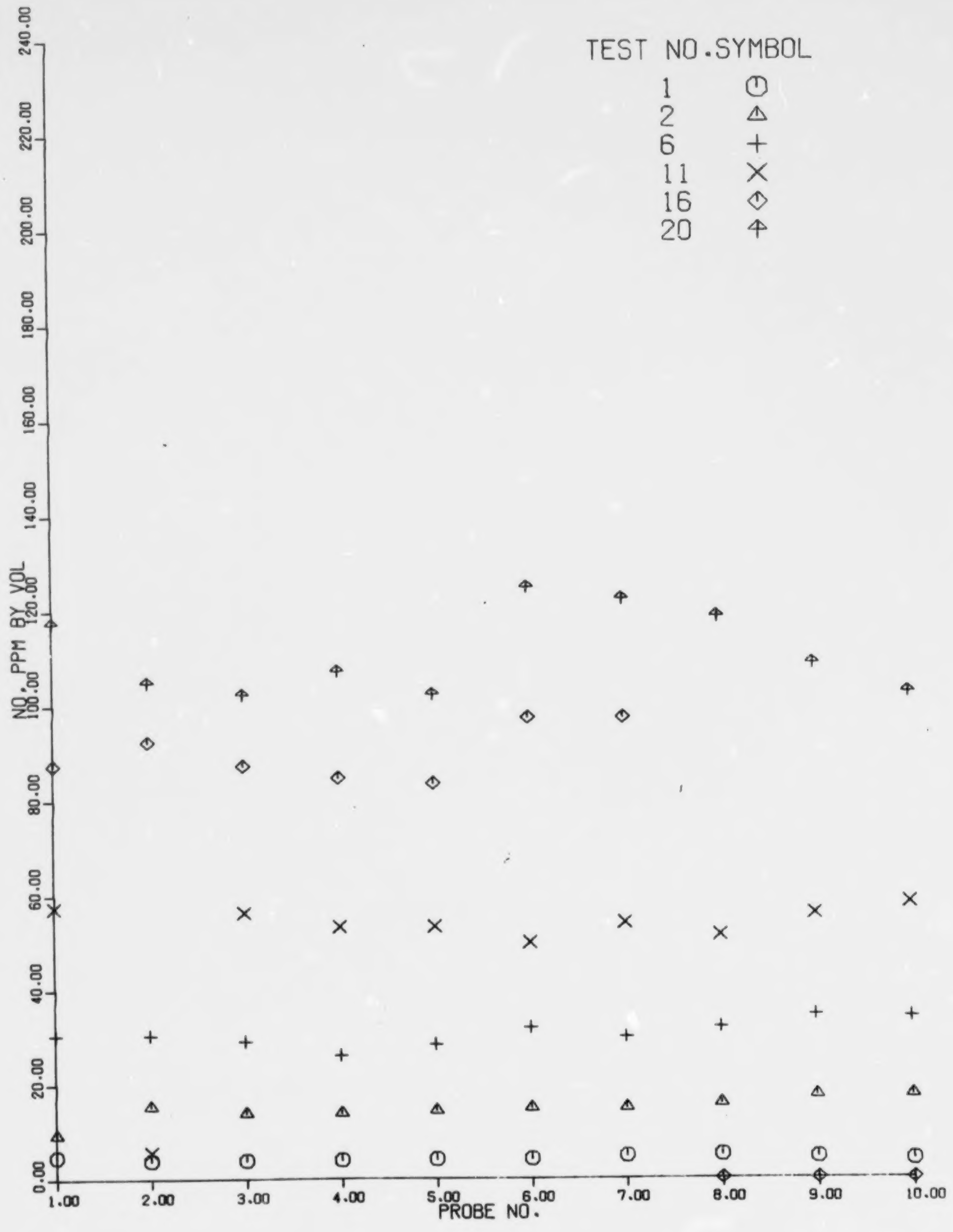

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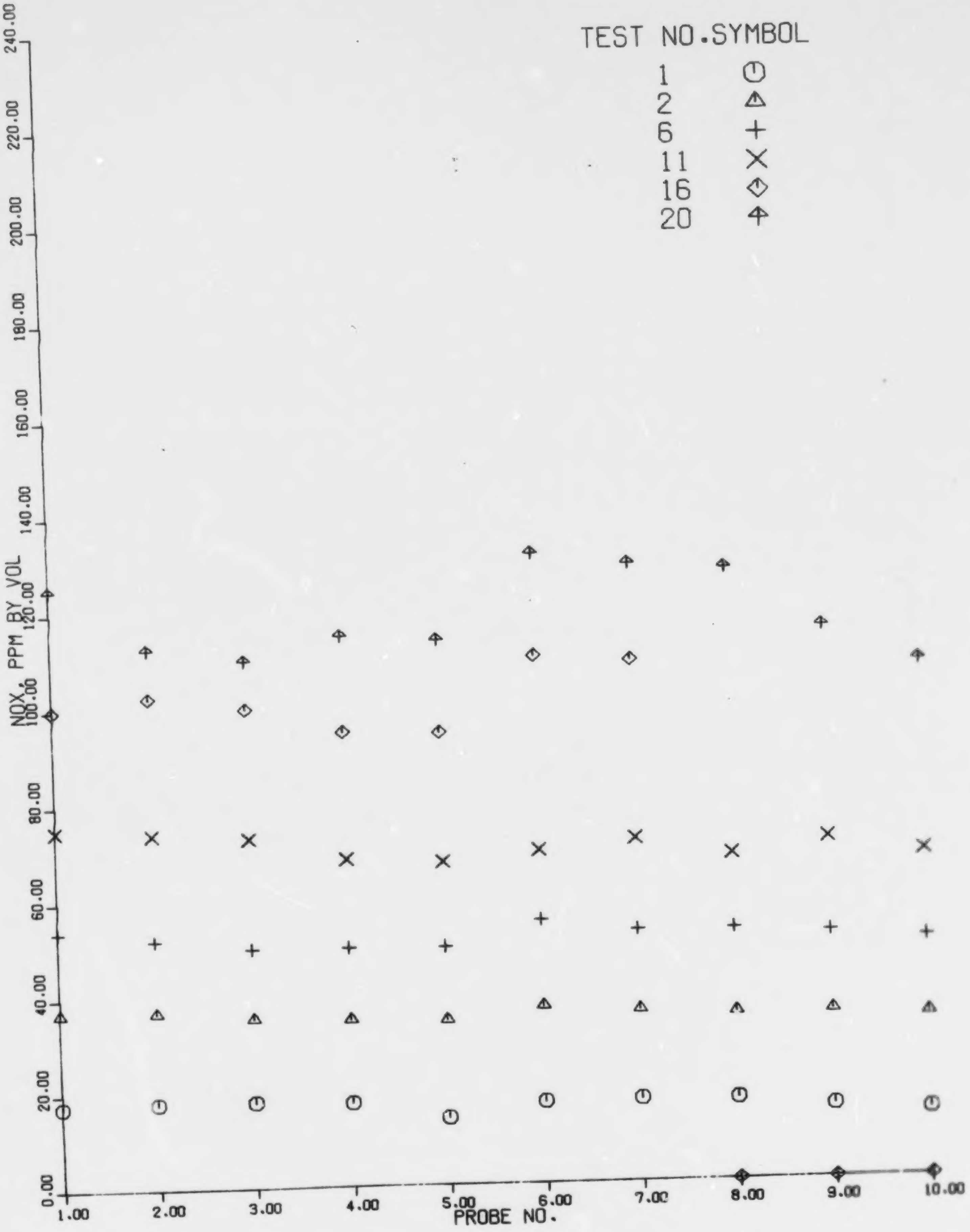

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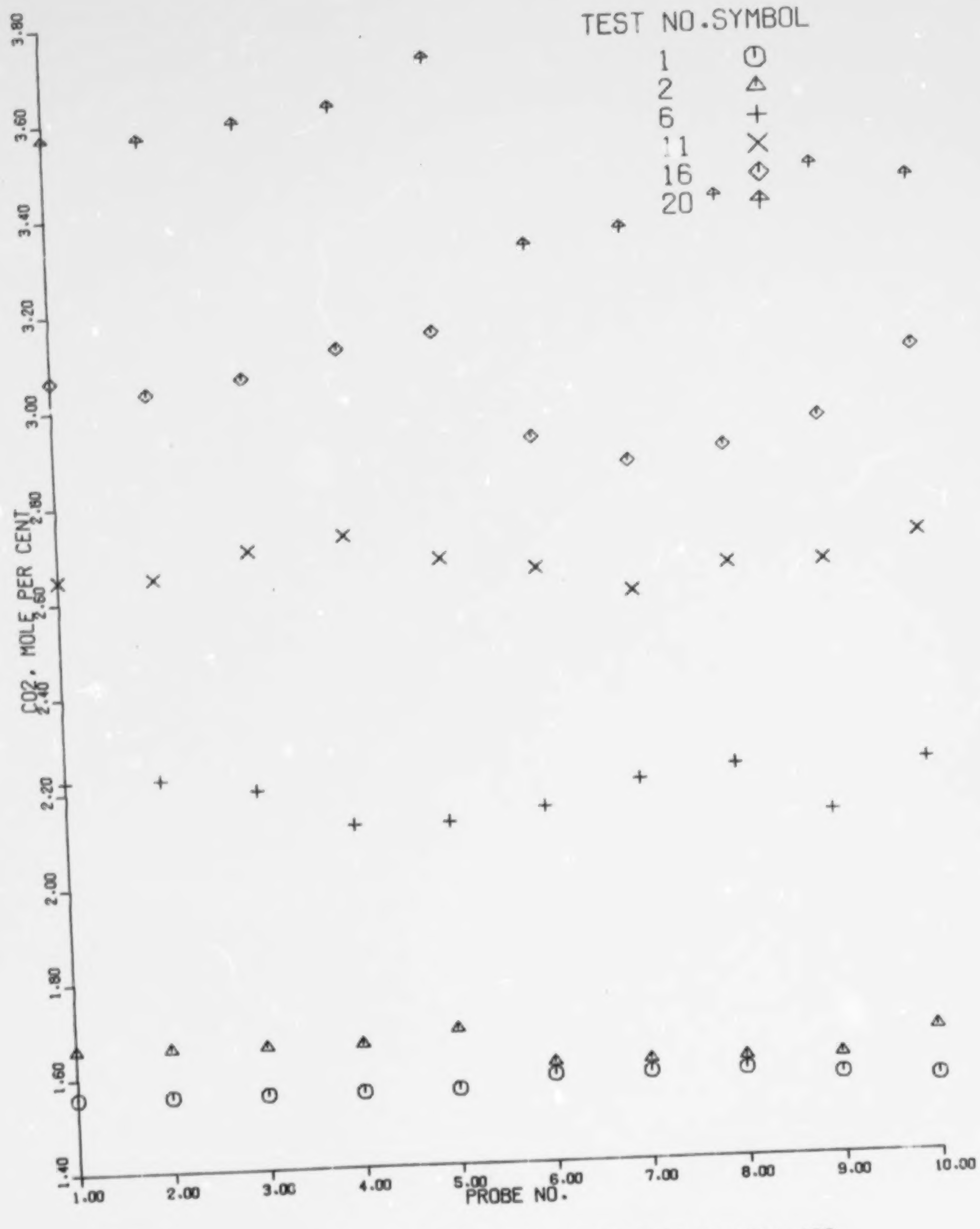

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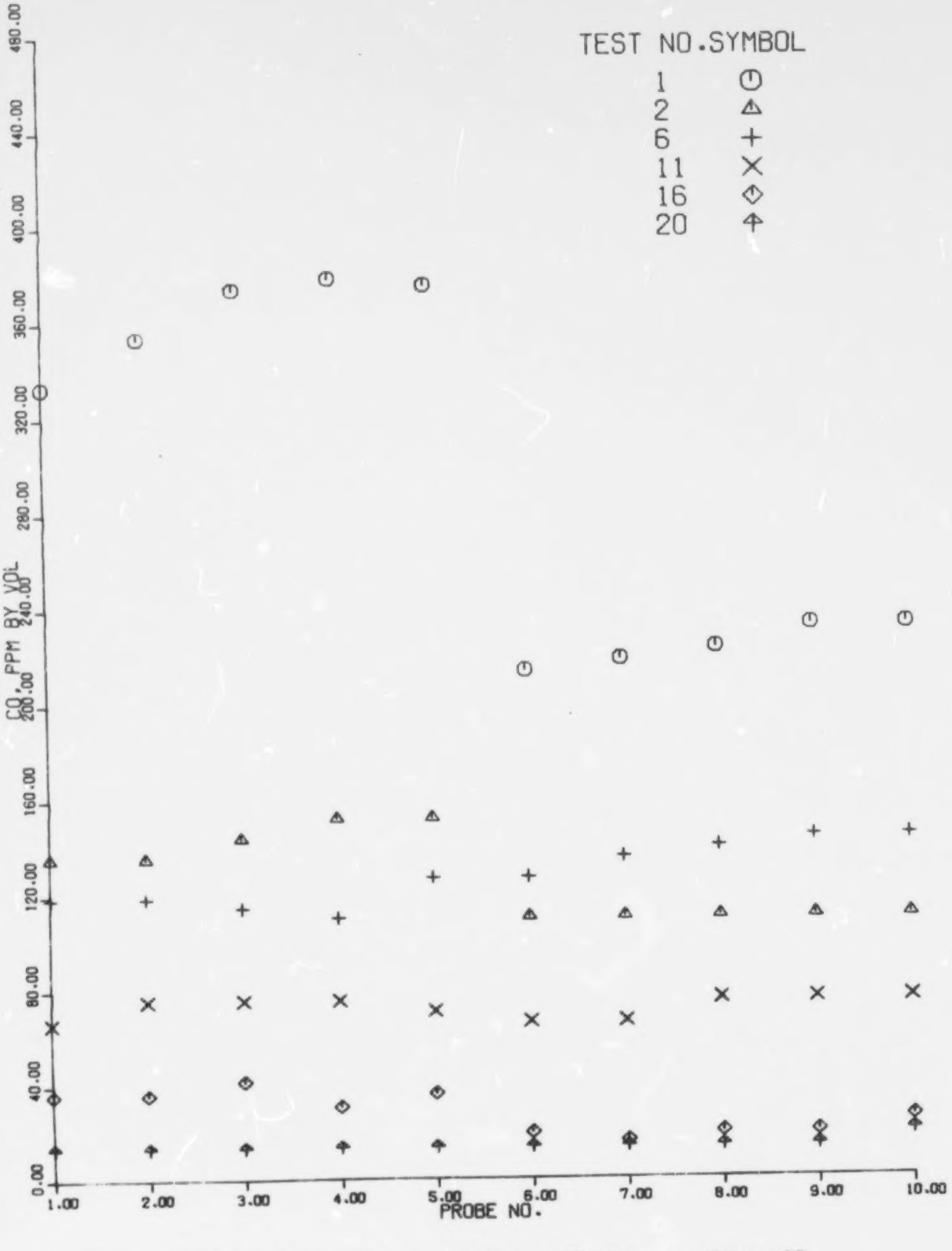

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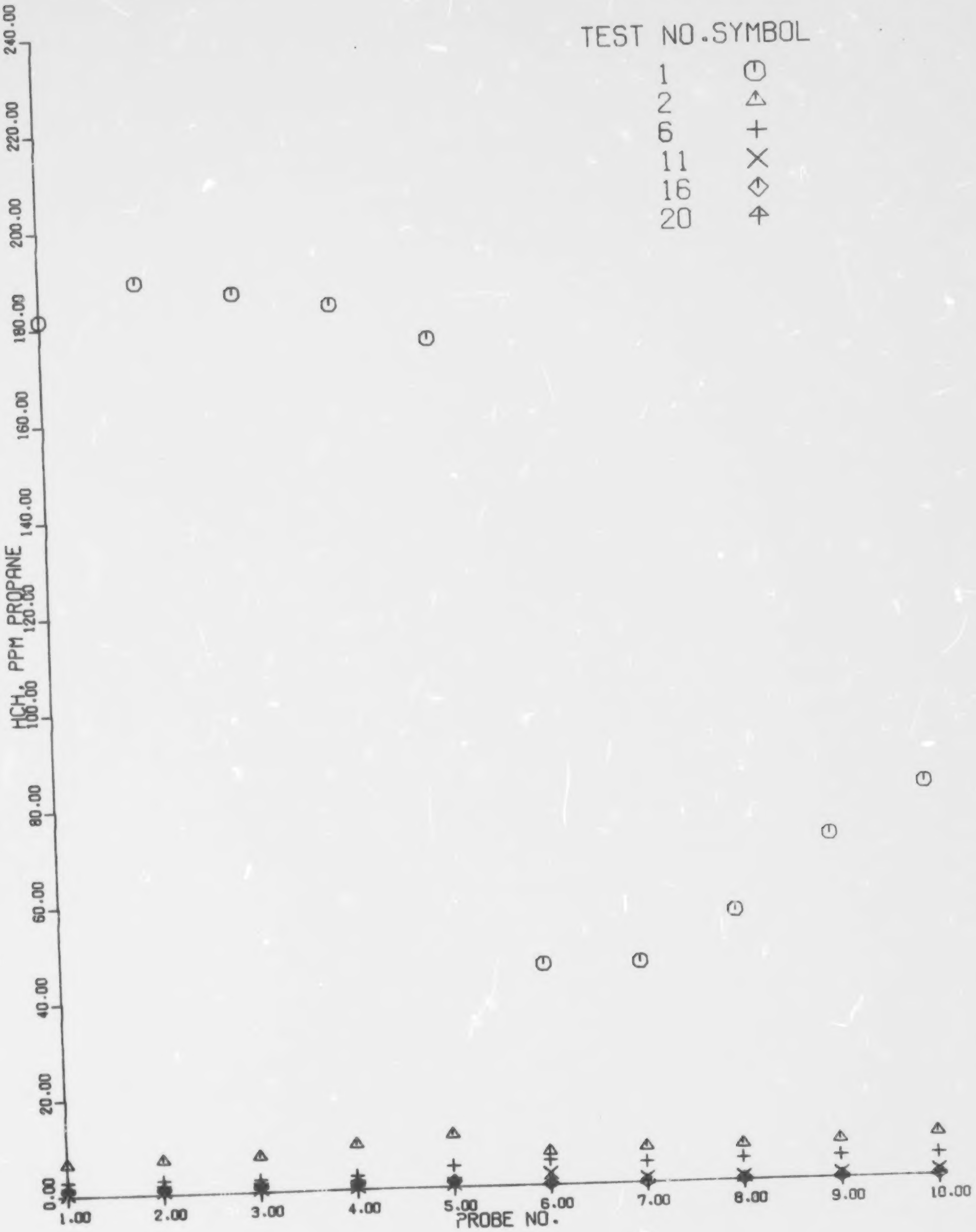

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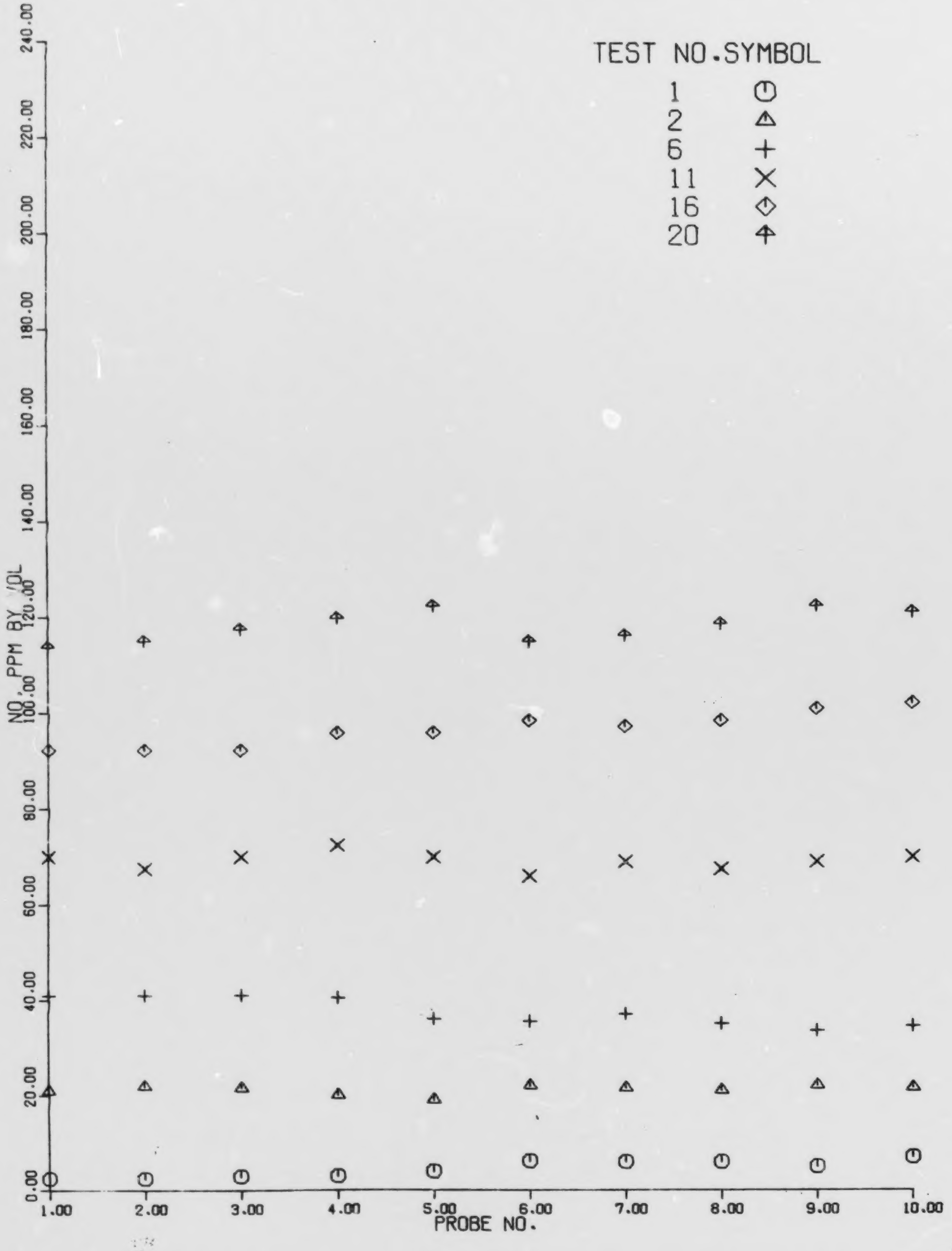

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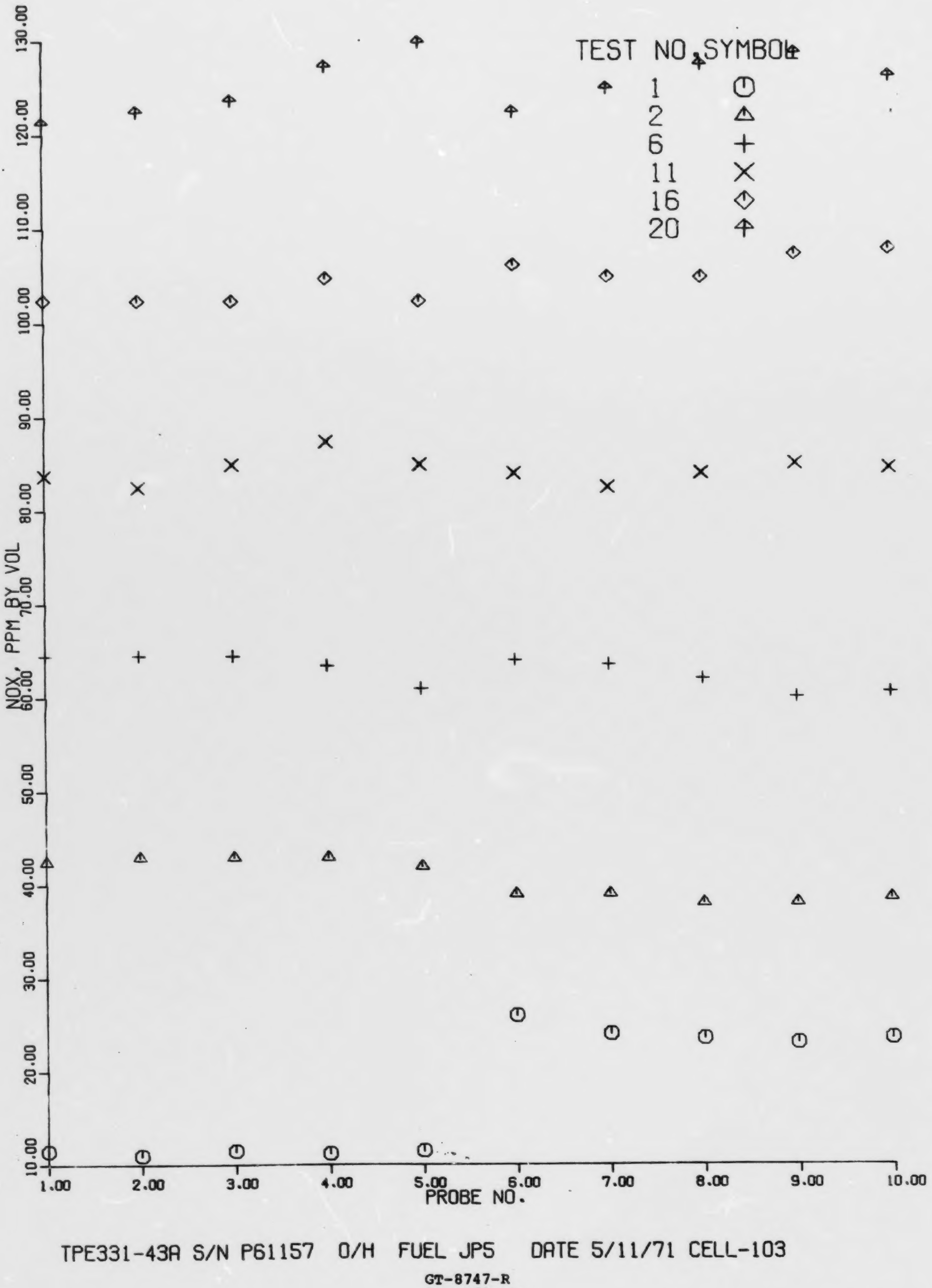

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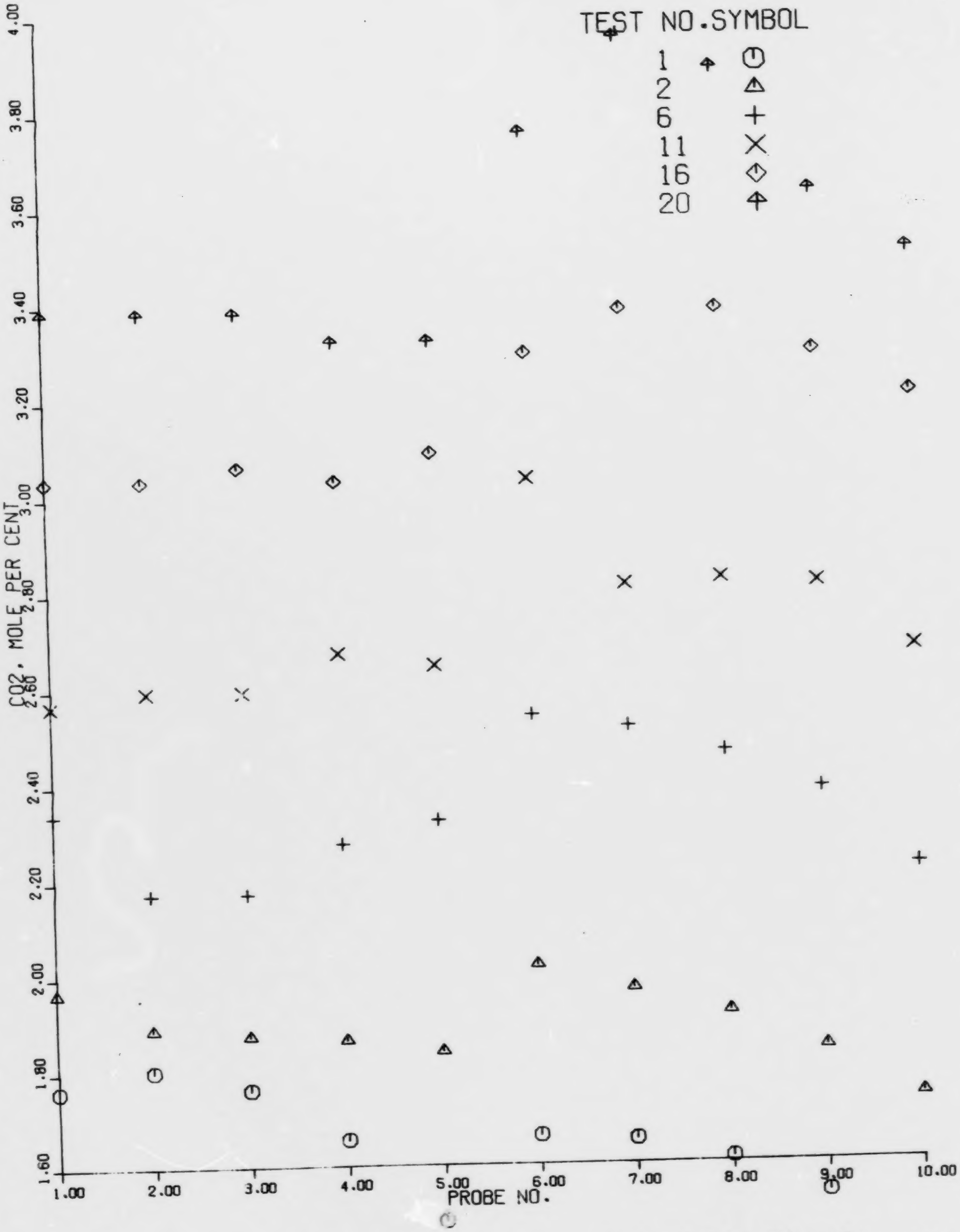

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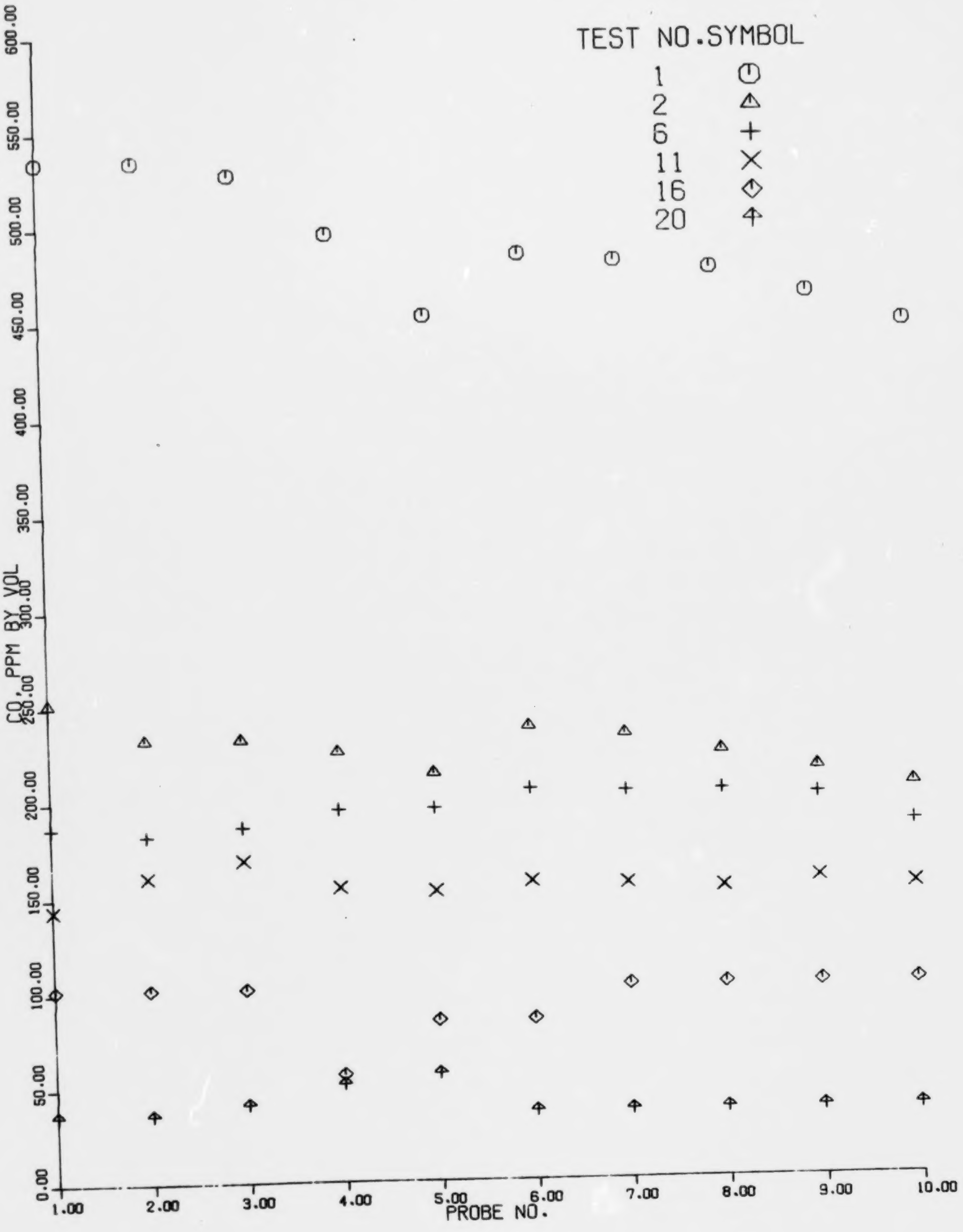

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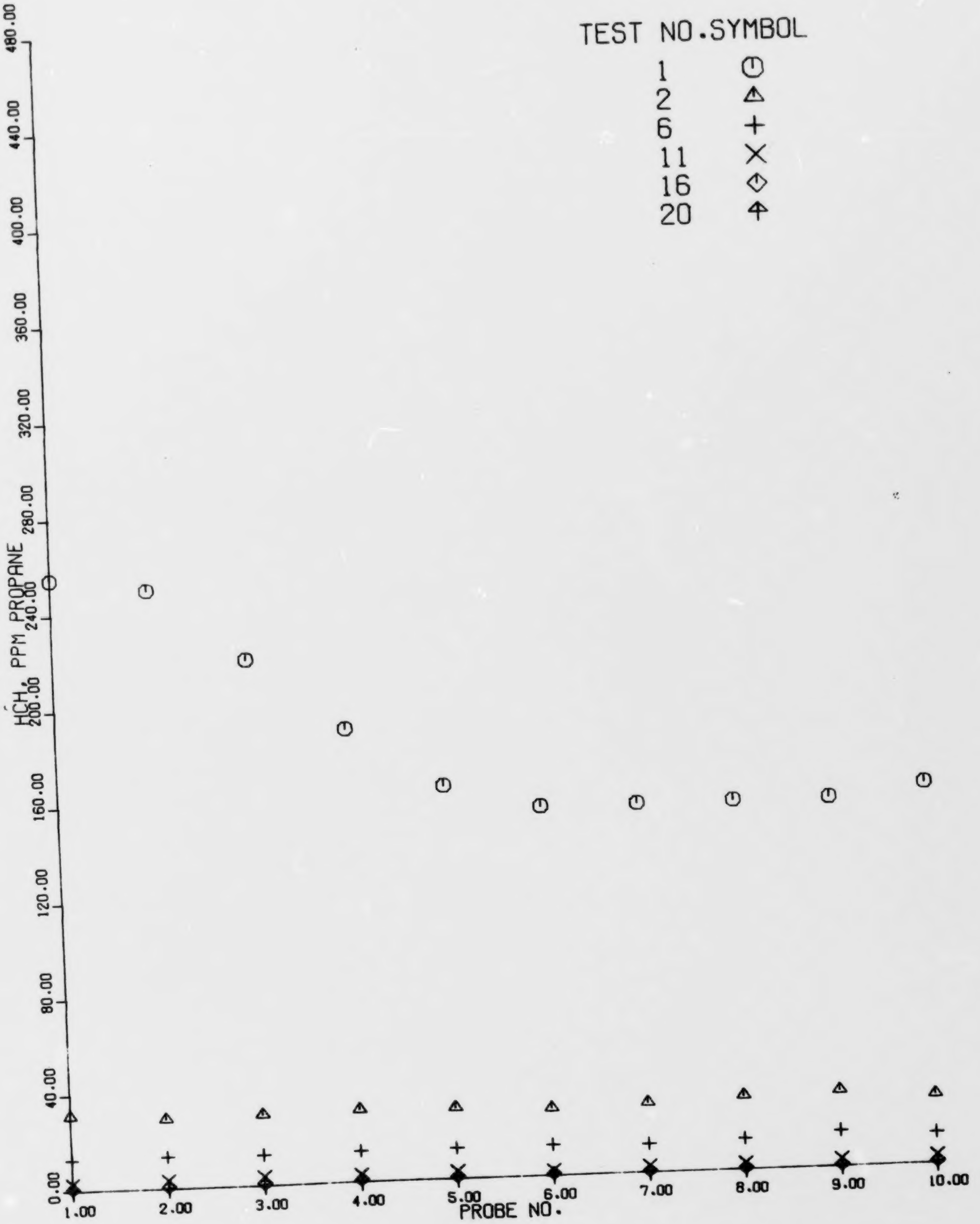

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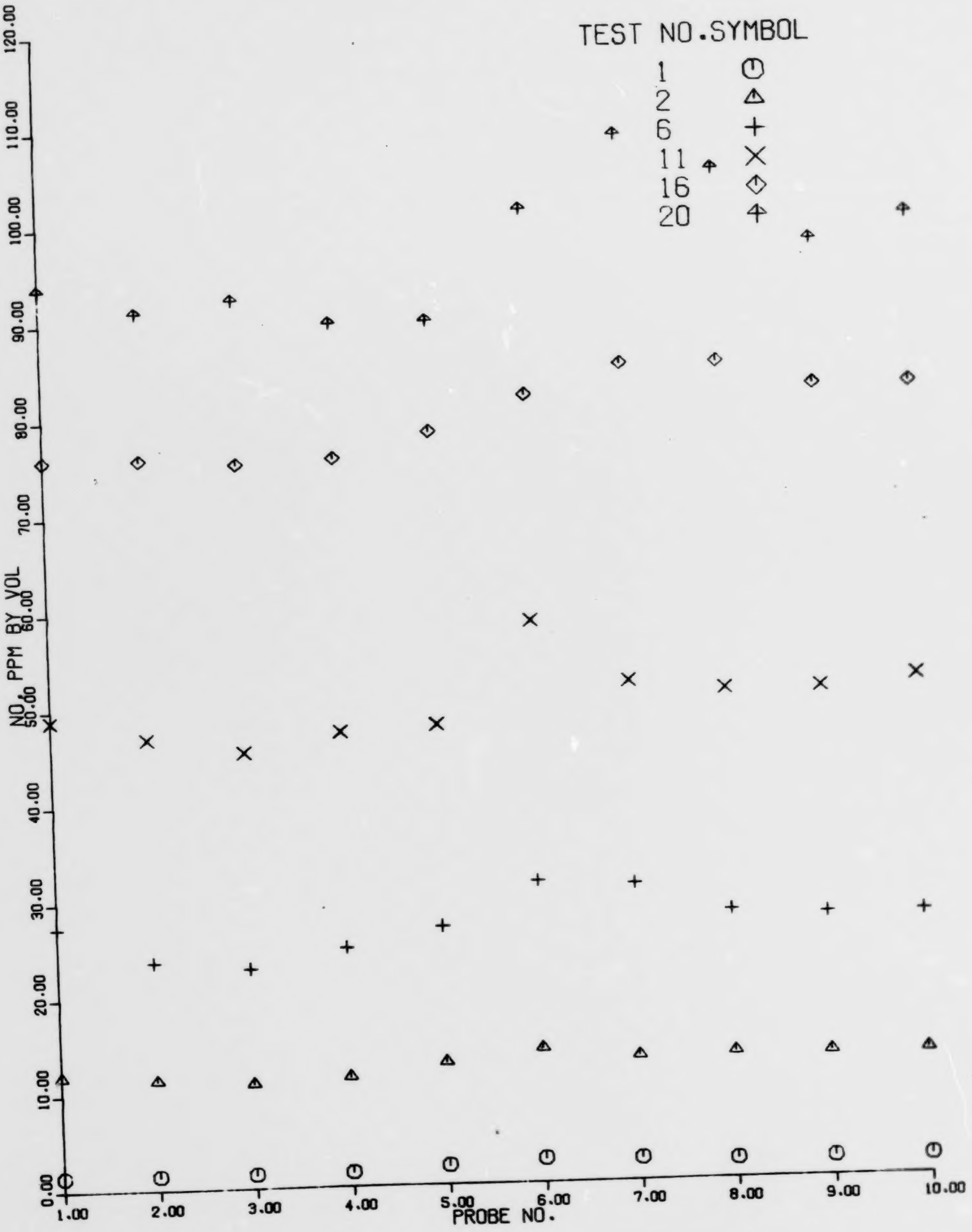

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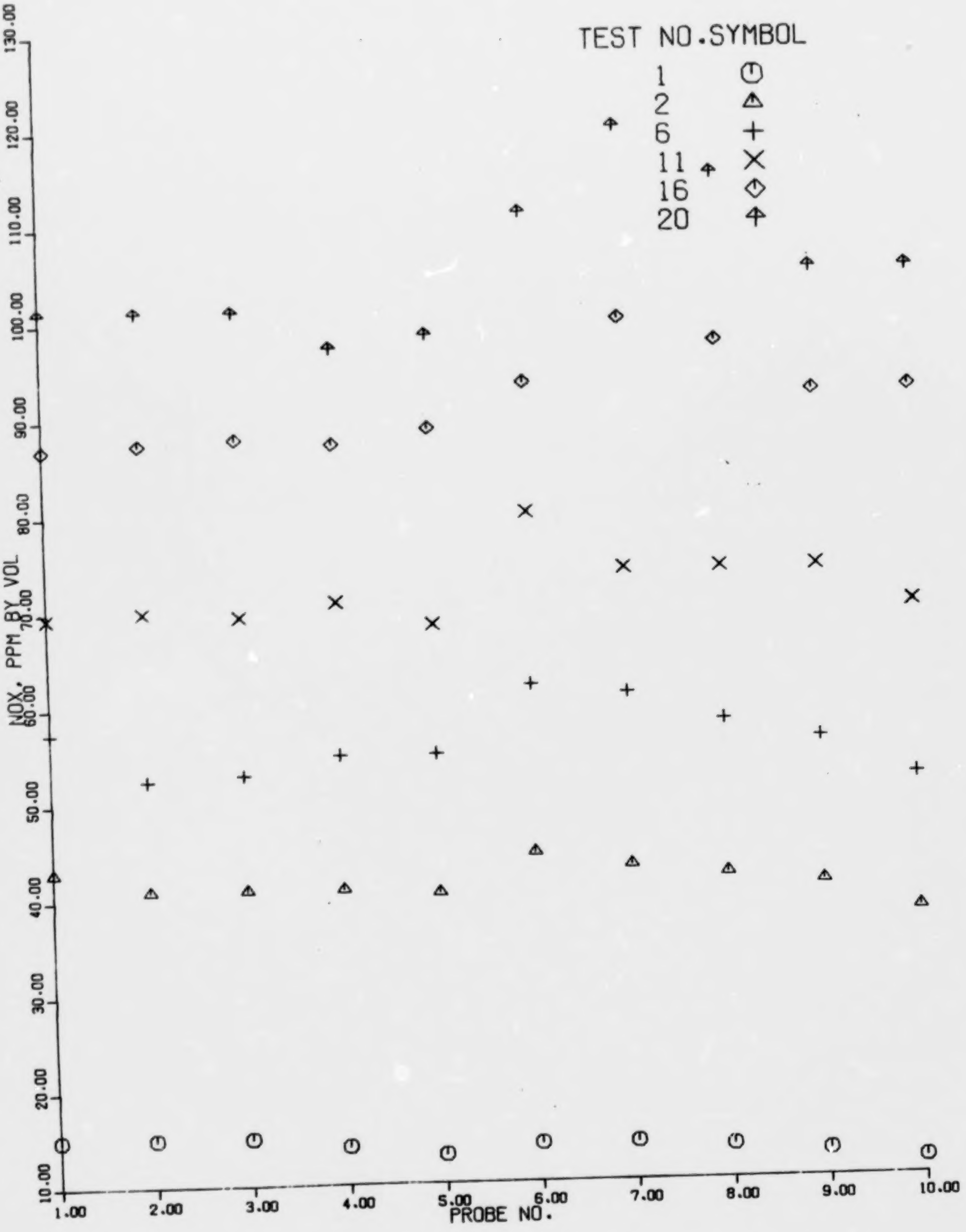

T76-G-410 S/N GE 00790 O/H FUEL JP5 DATE 5/6/71 CELL 104

GROUP 2

SMALL AUXILIARY POWER UNITS

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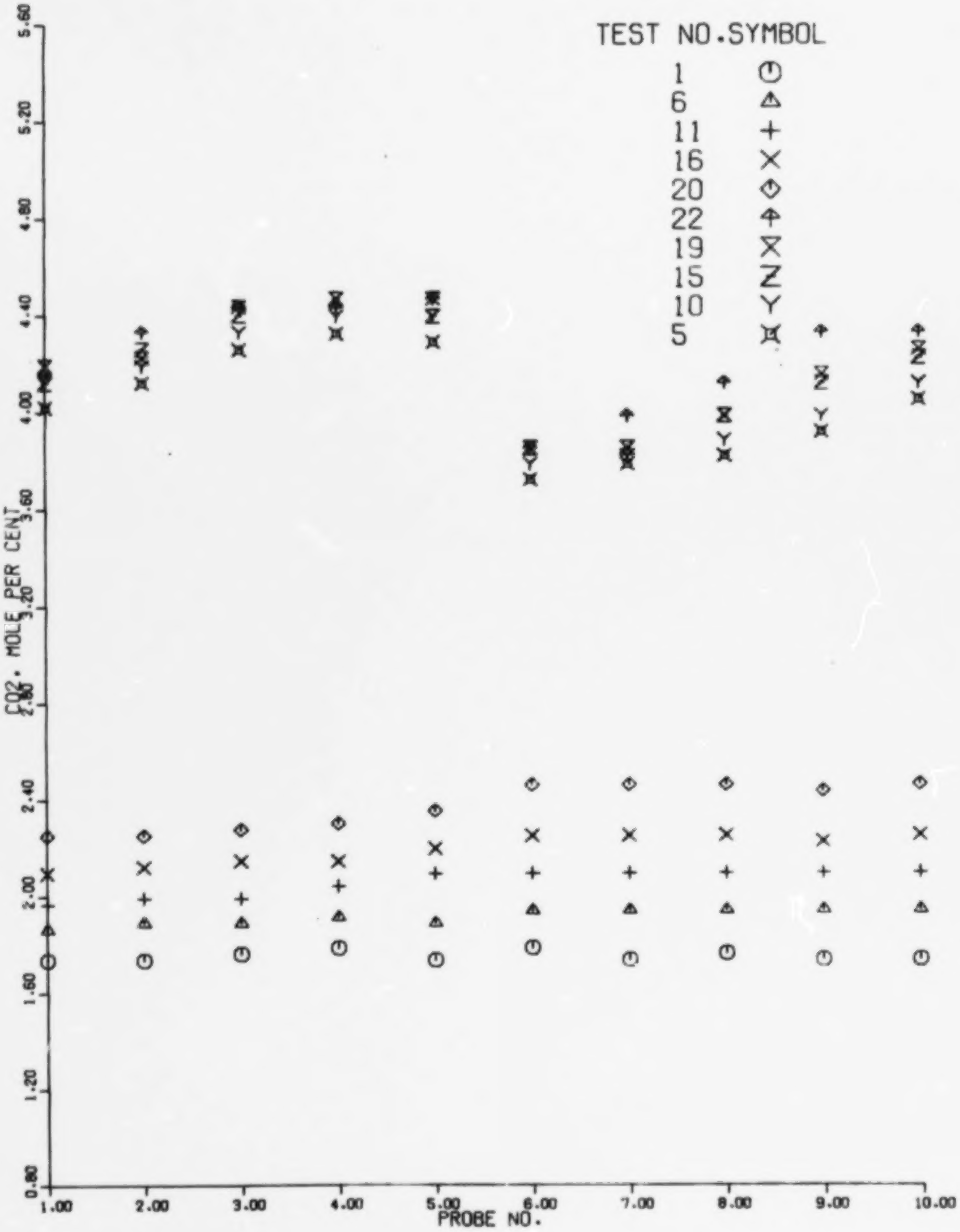

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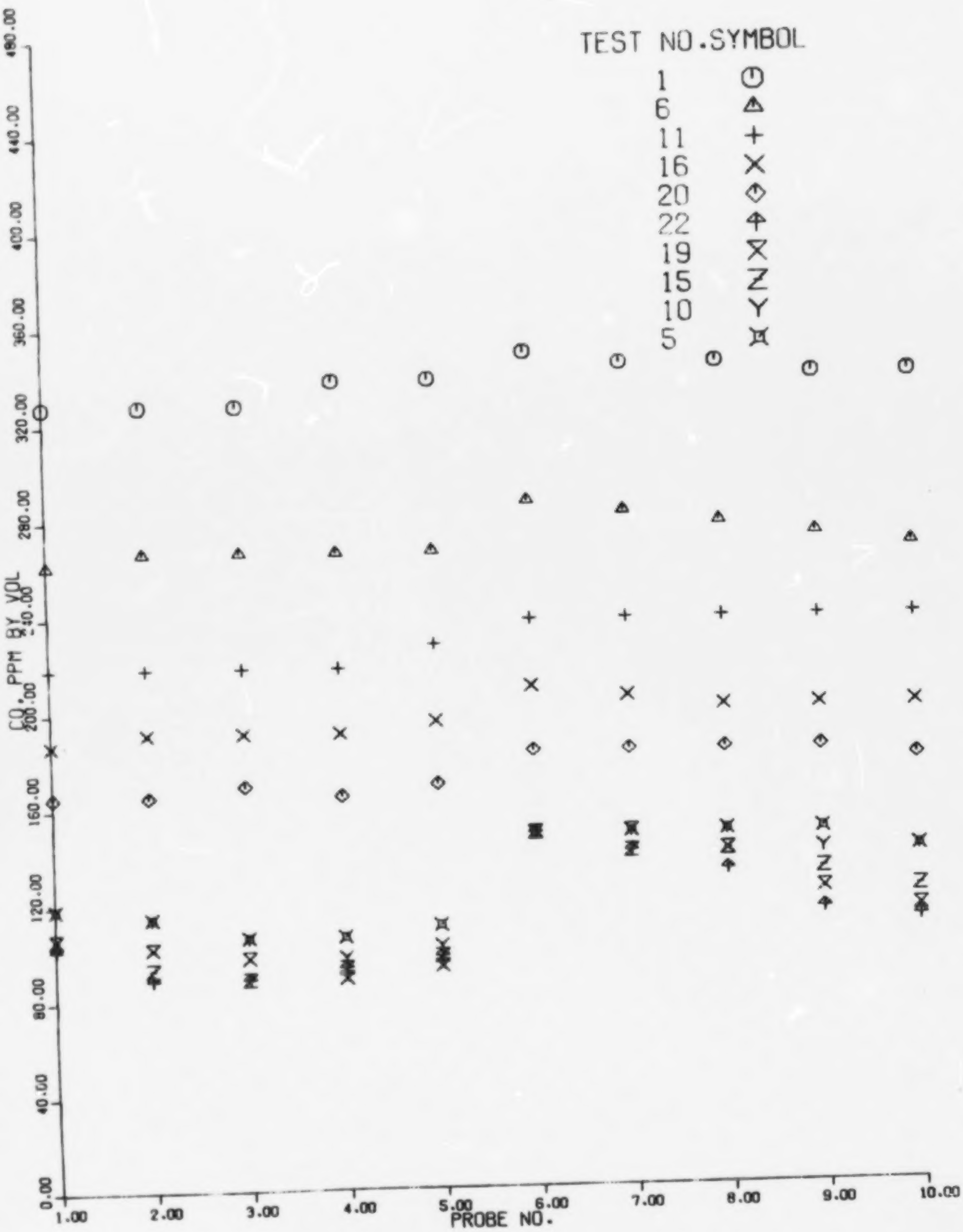

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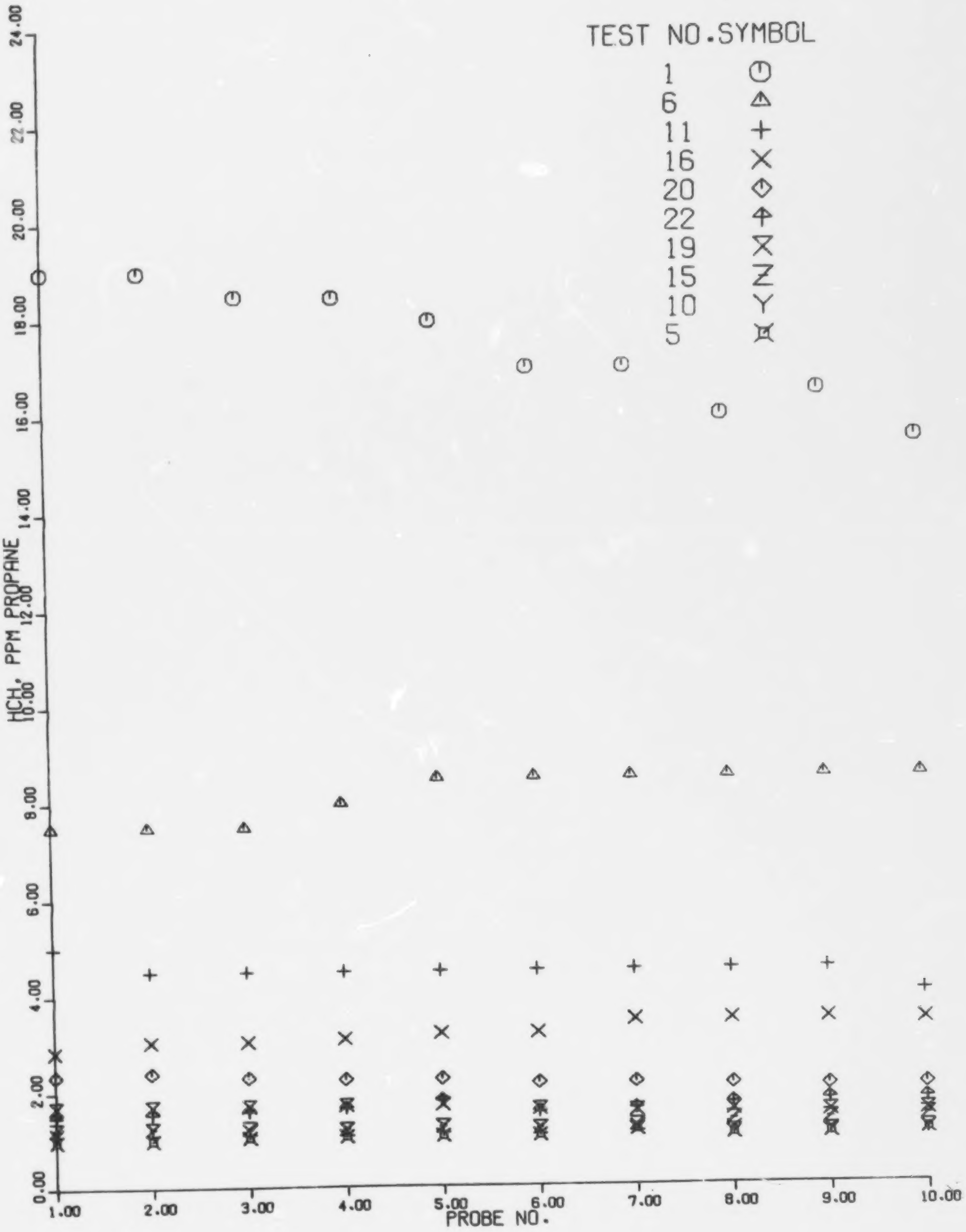

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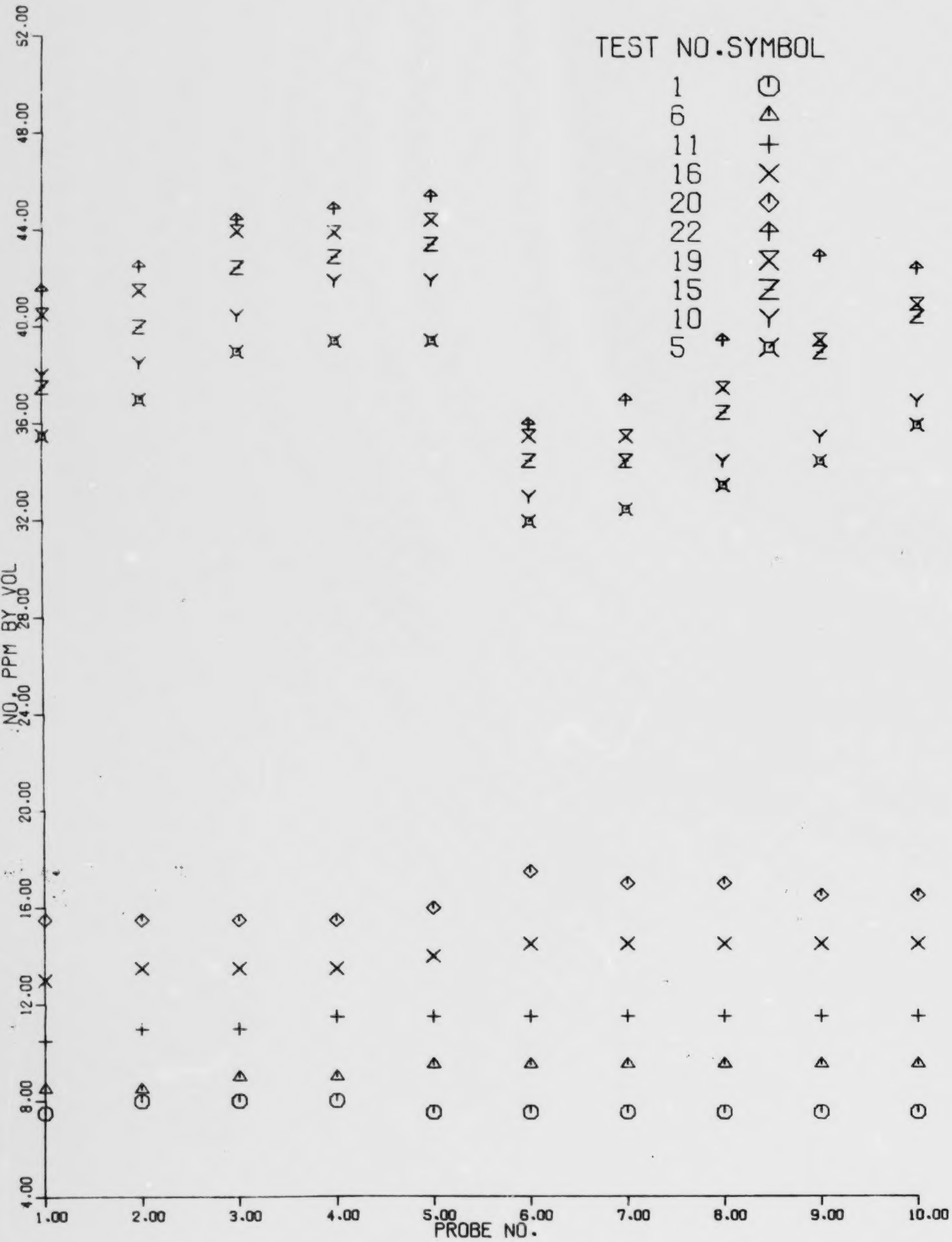

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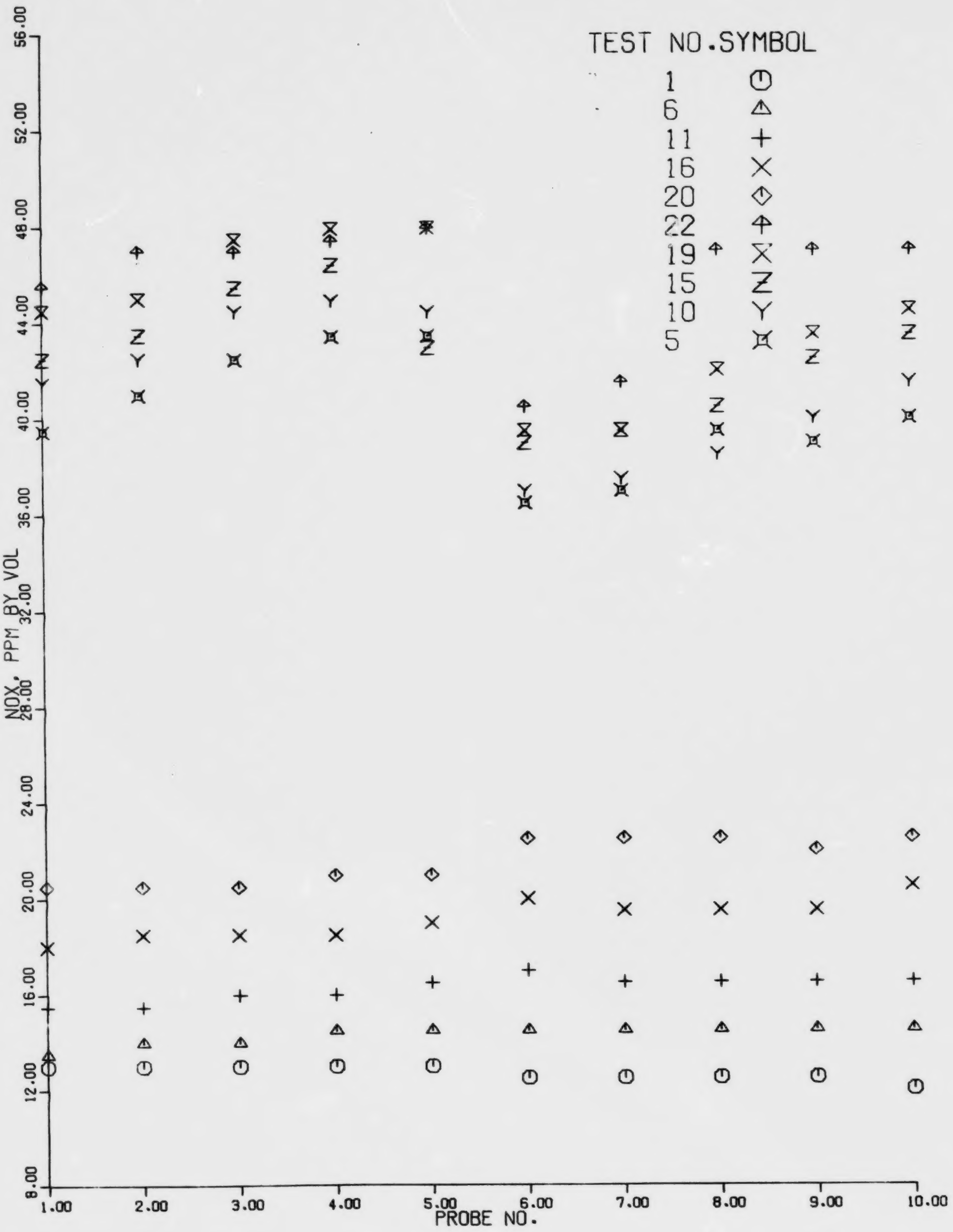

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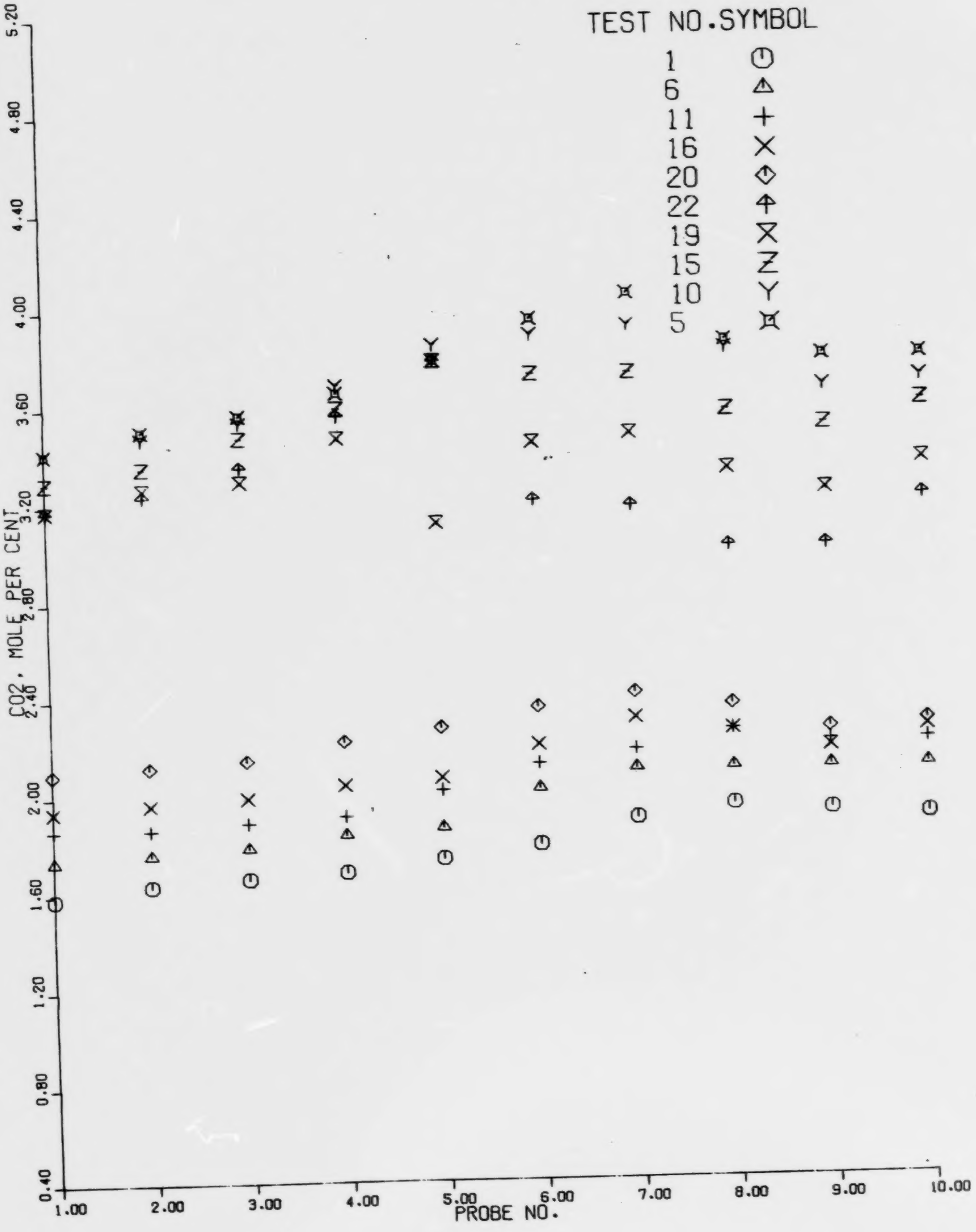

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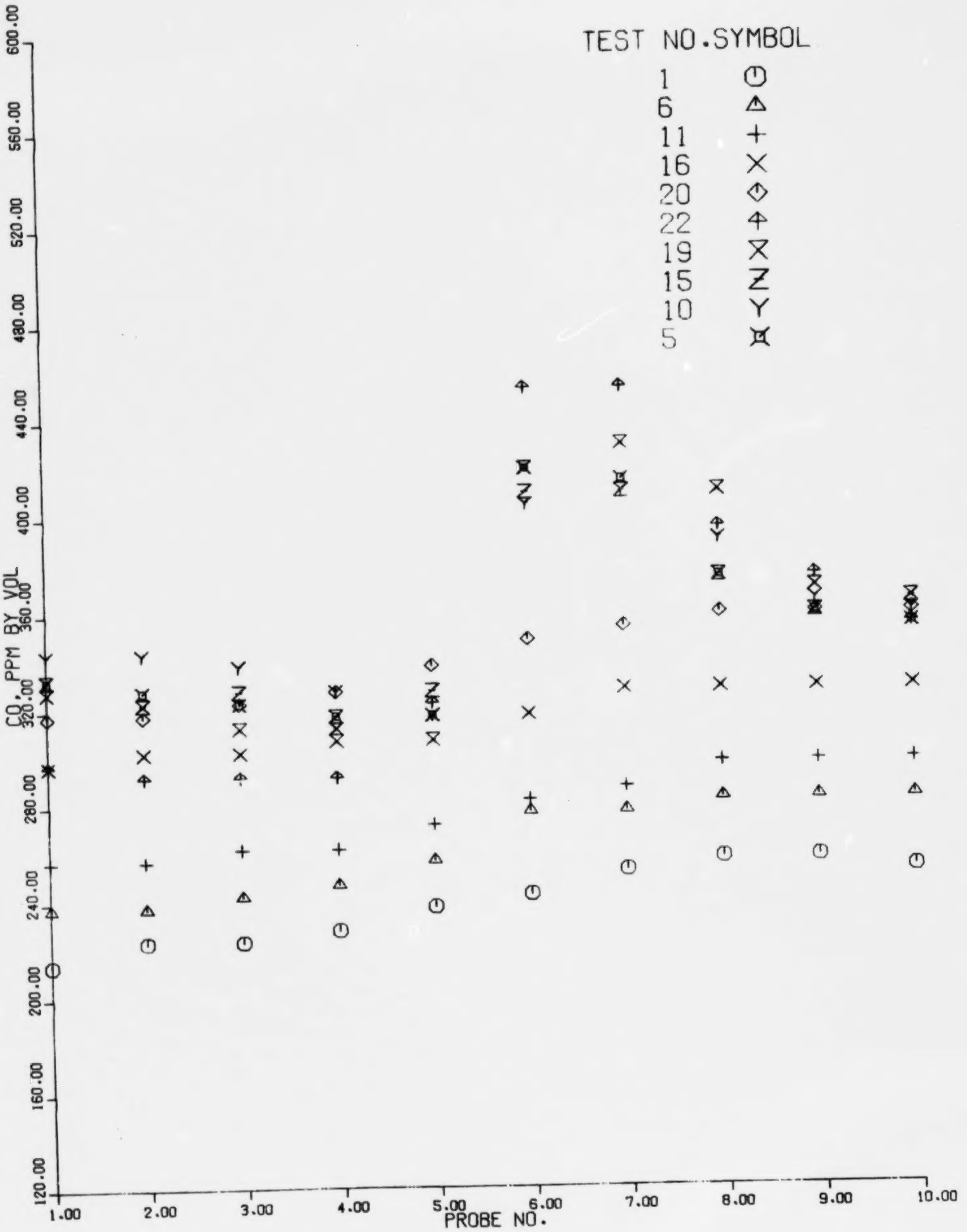

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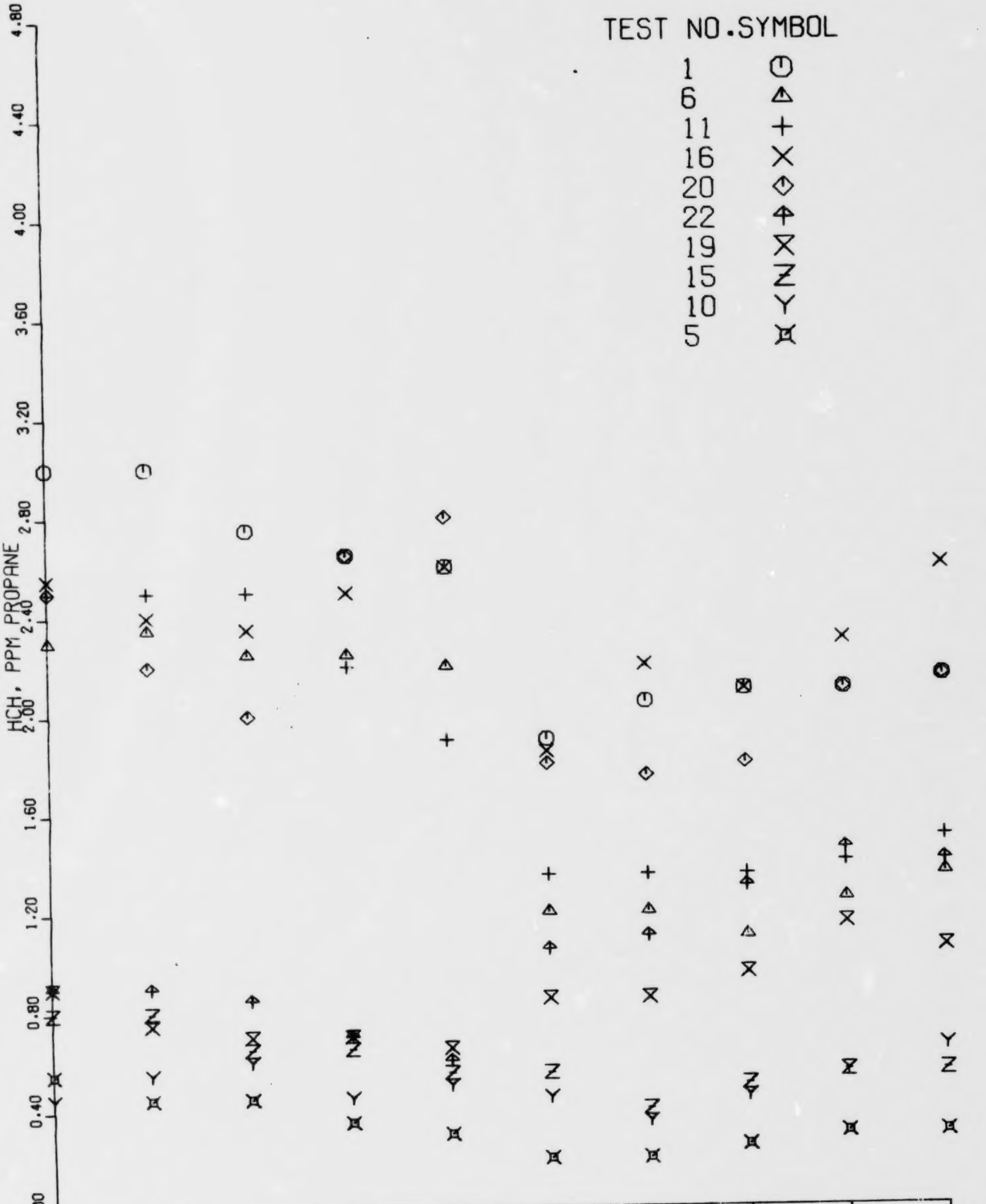

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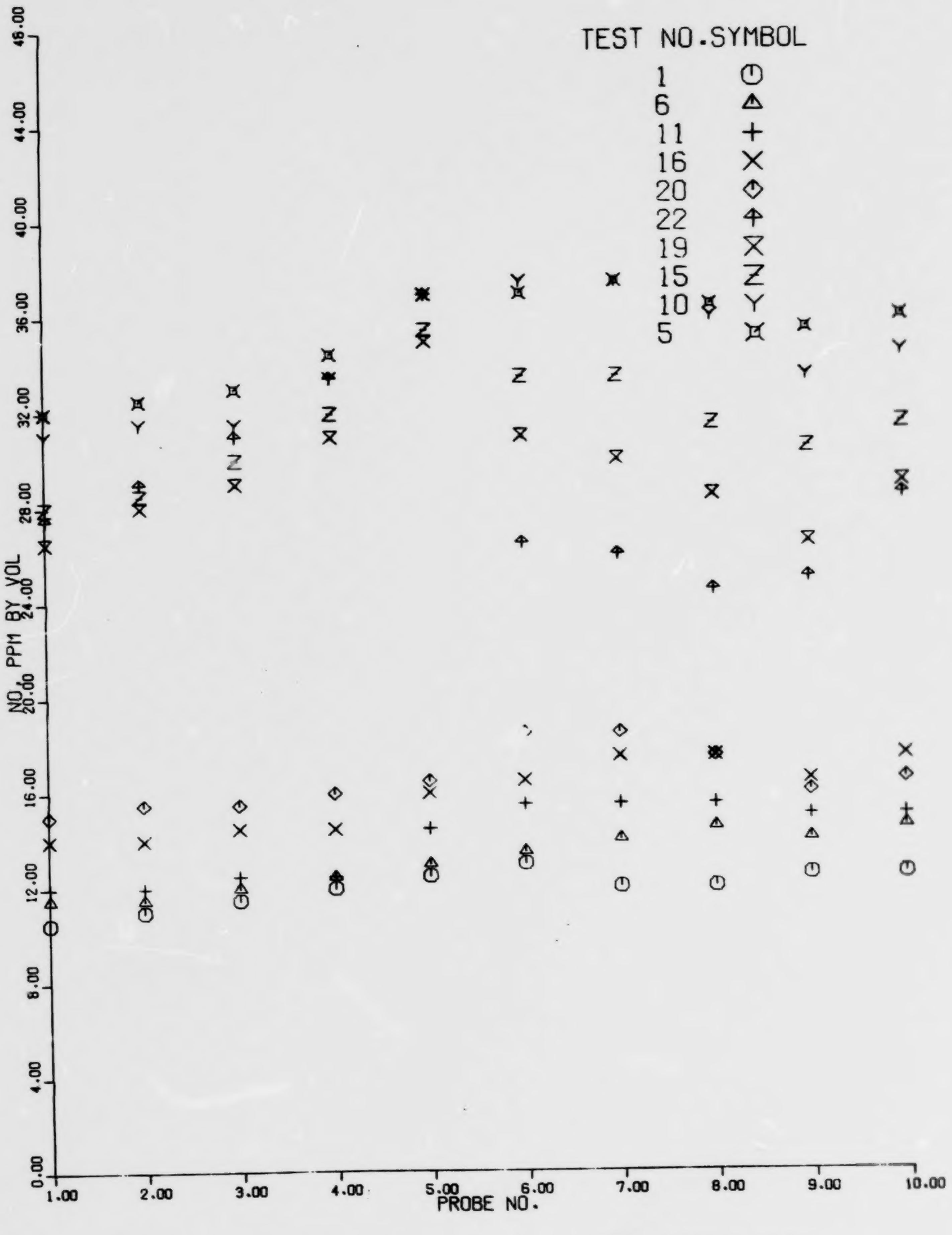

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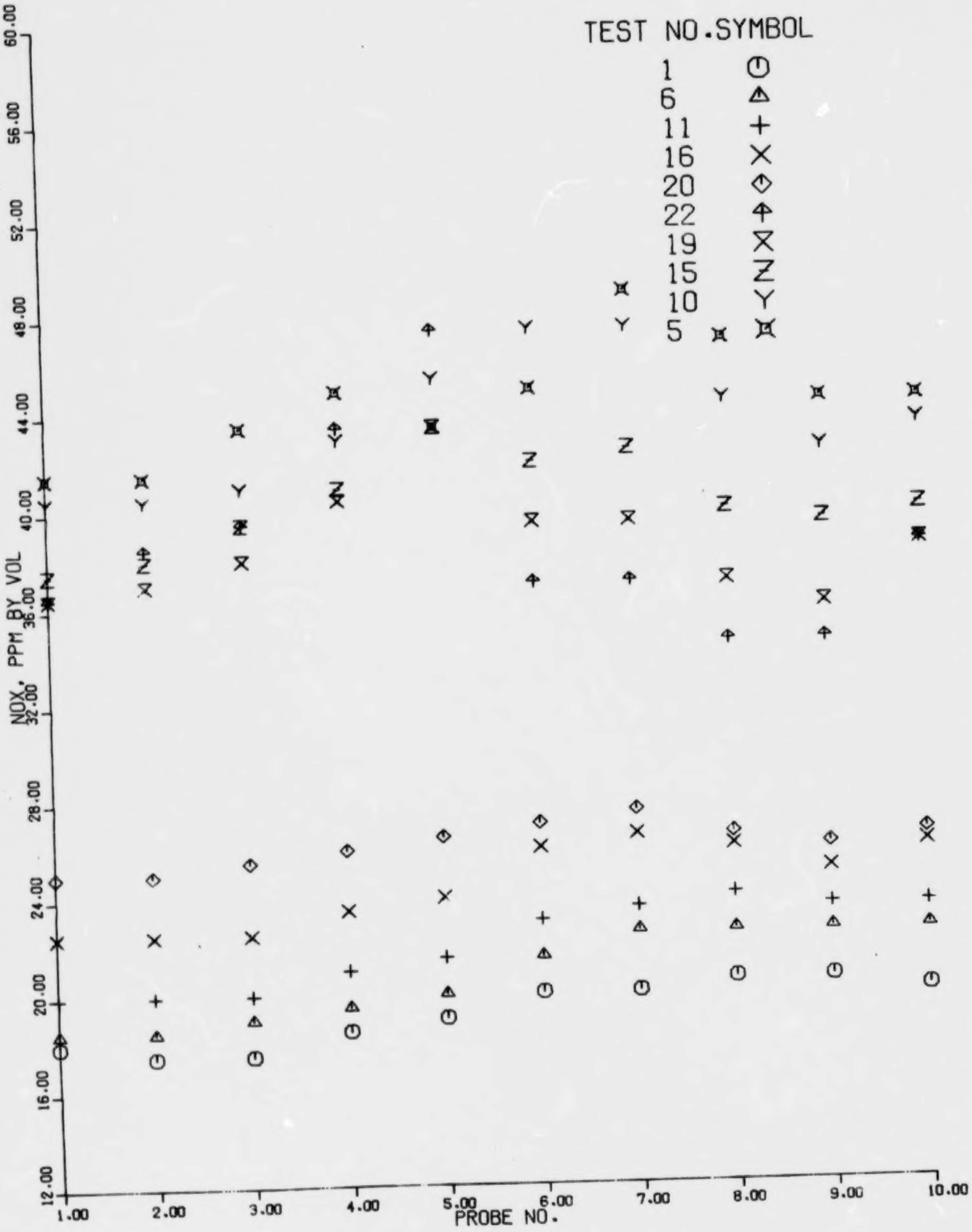

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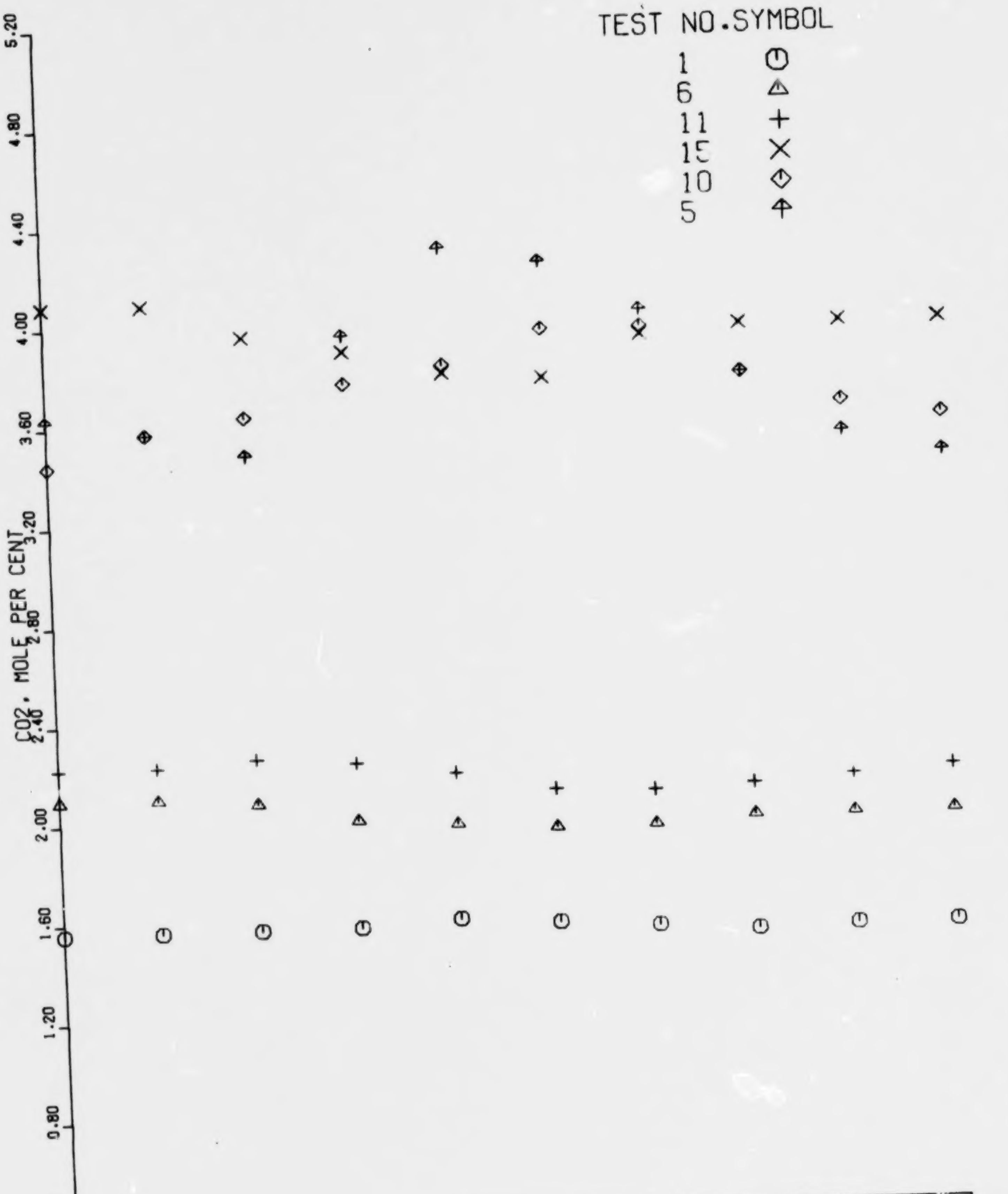
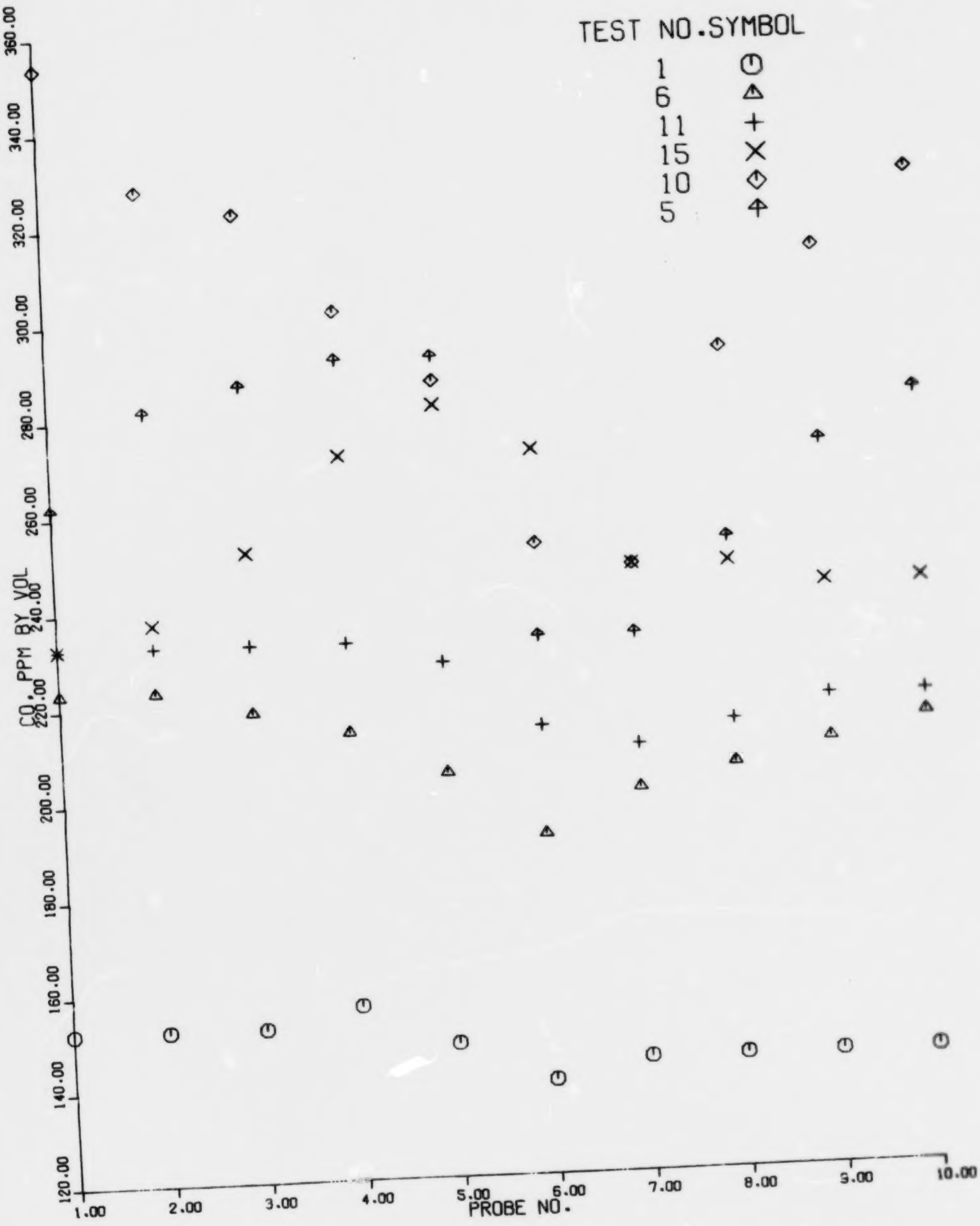


GTCP36-6 .S/N P-34696. O/H. FUEL JP5 DATE 5/14/71 CELL C-102



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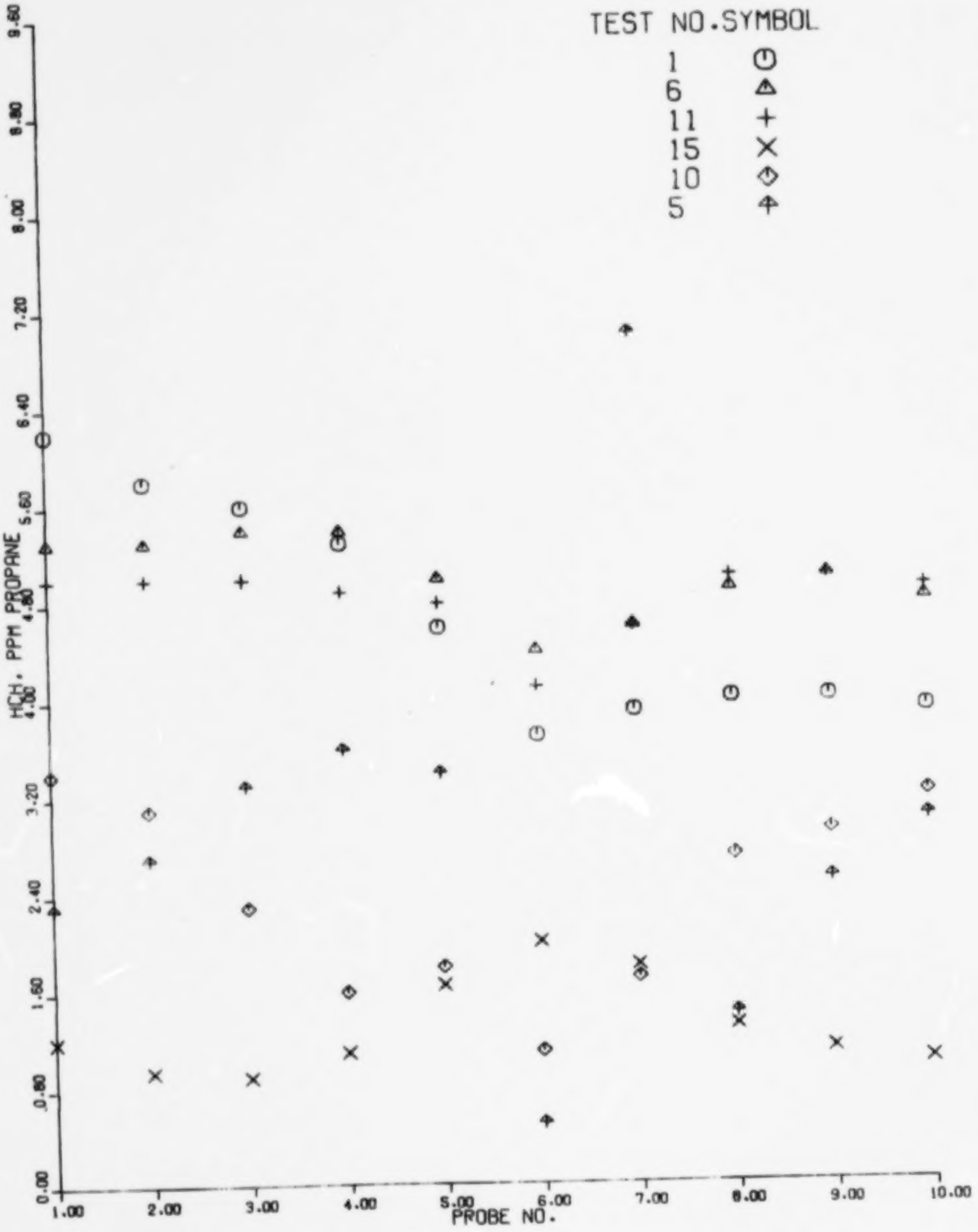

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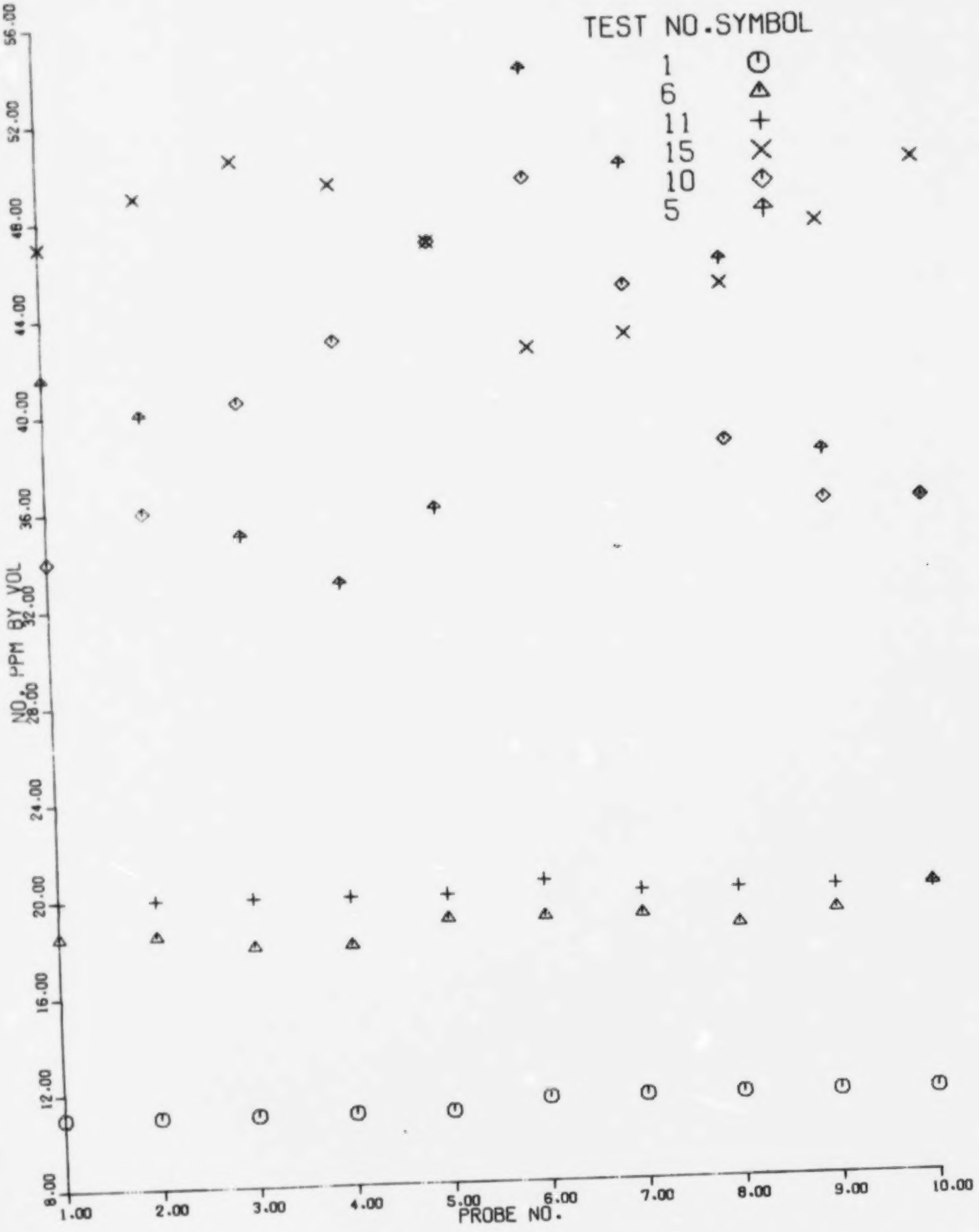

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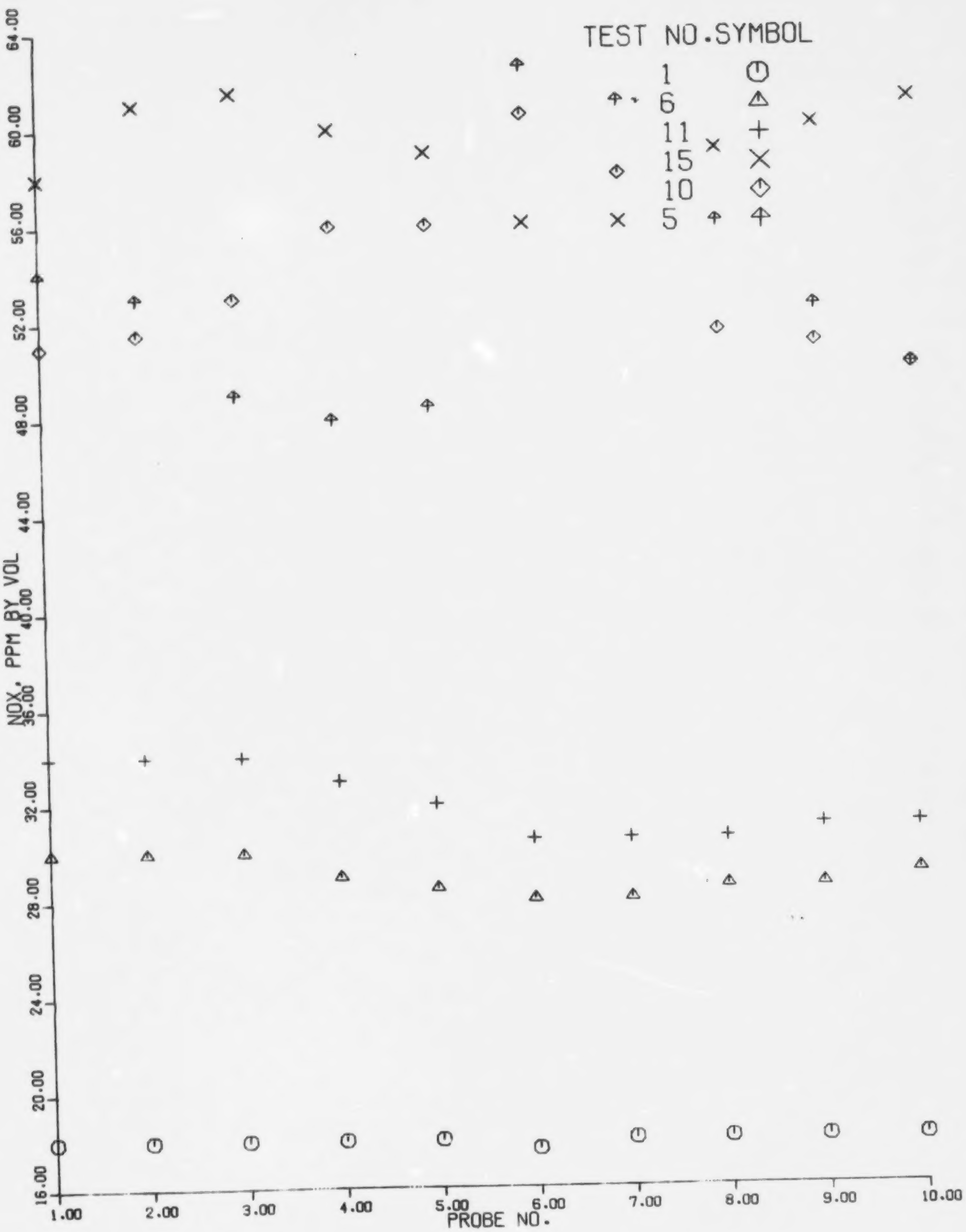

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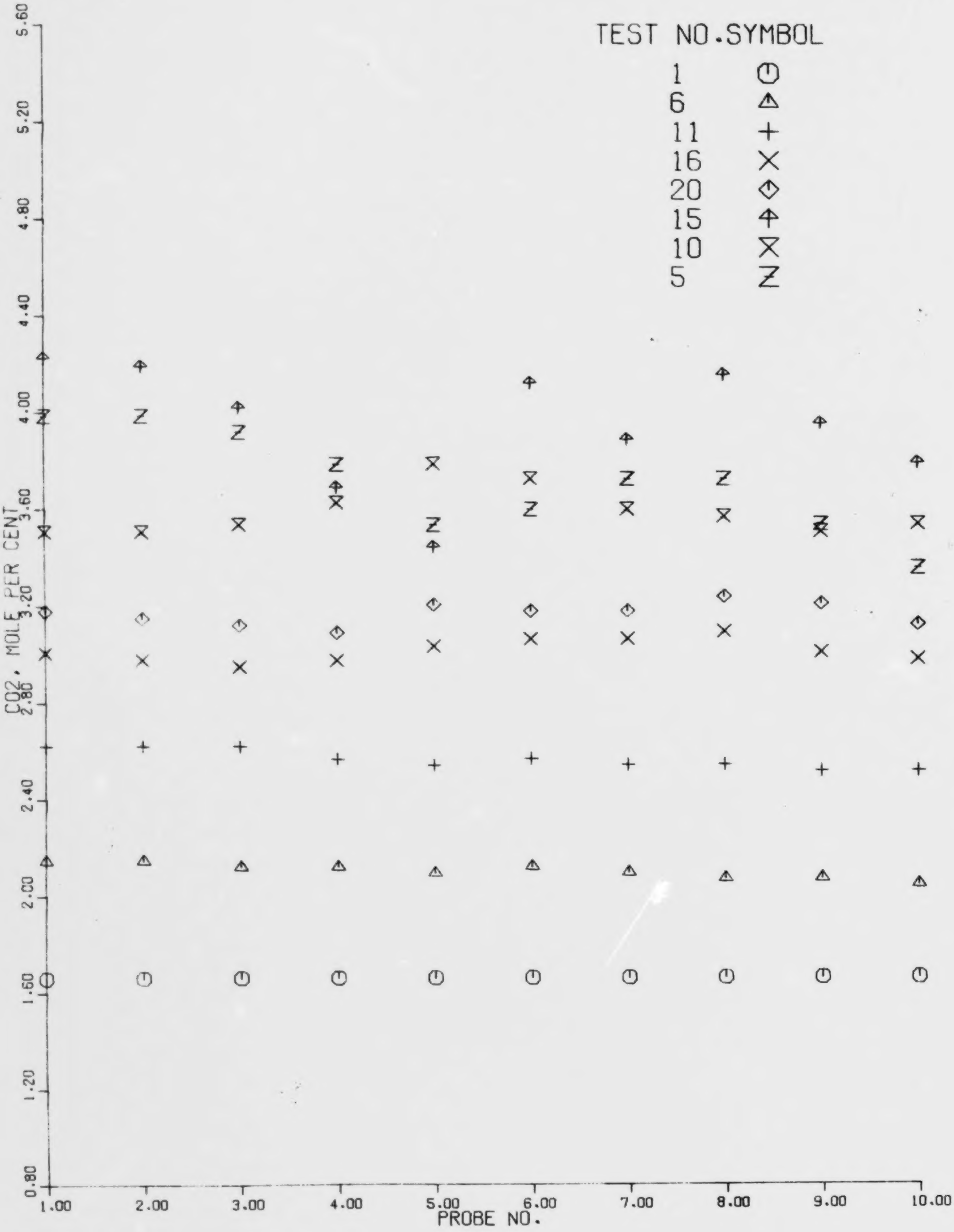

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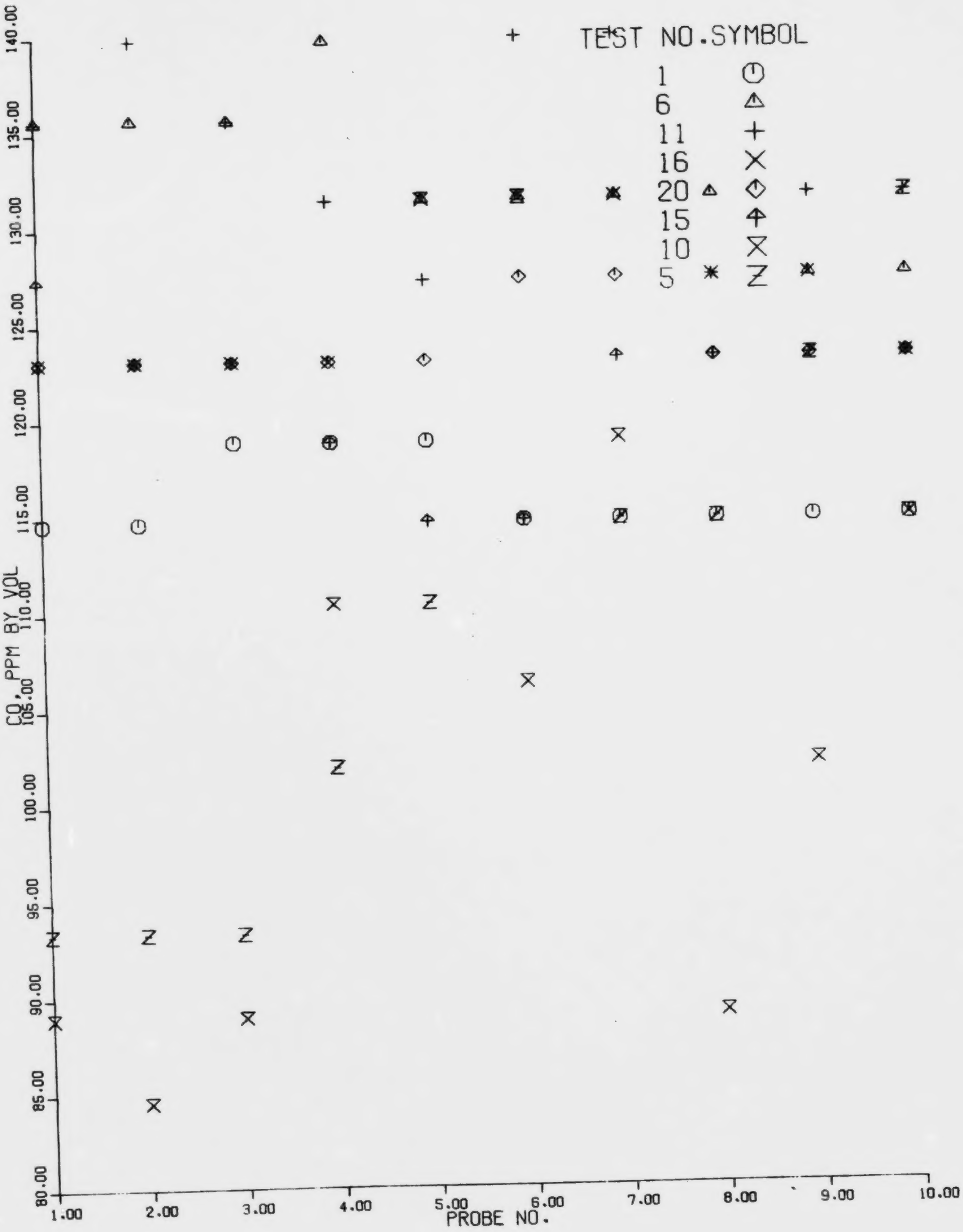

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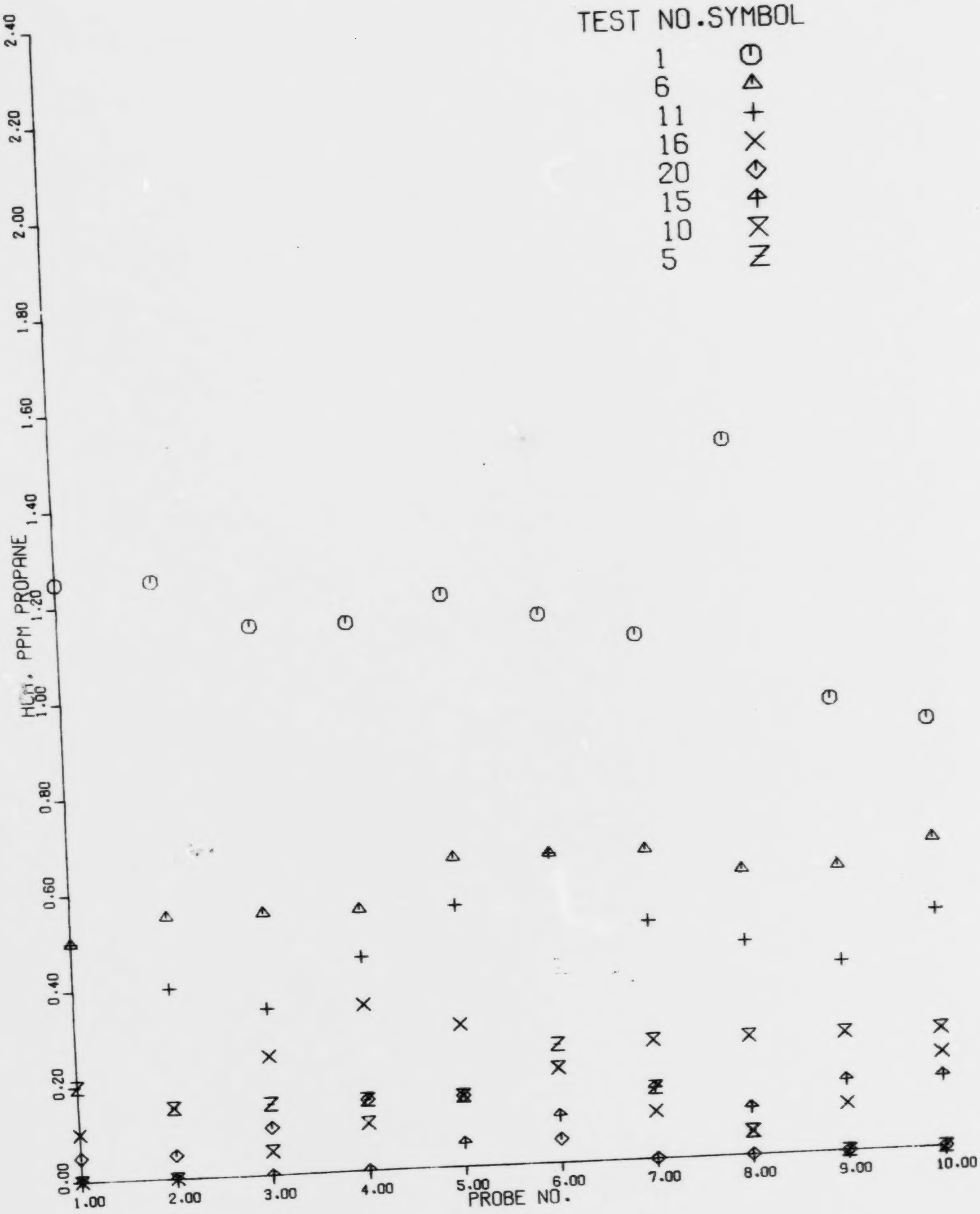

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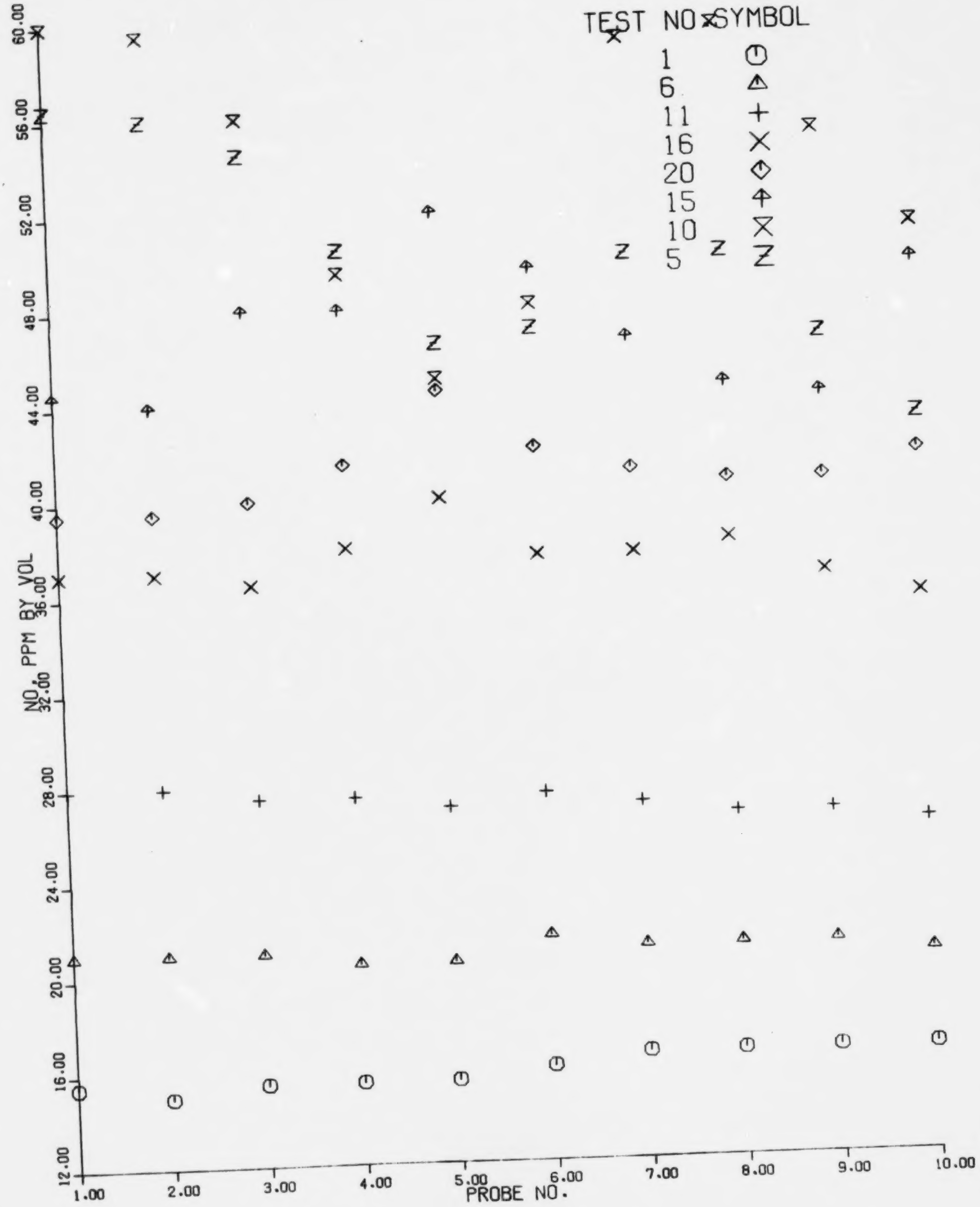

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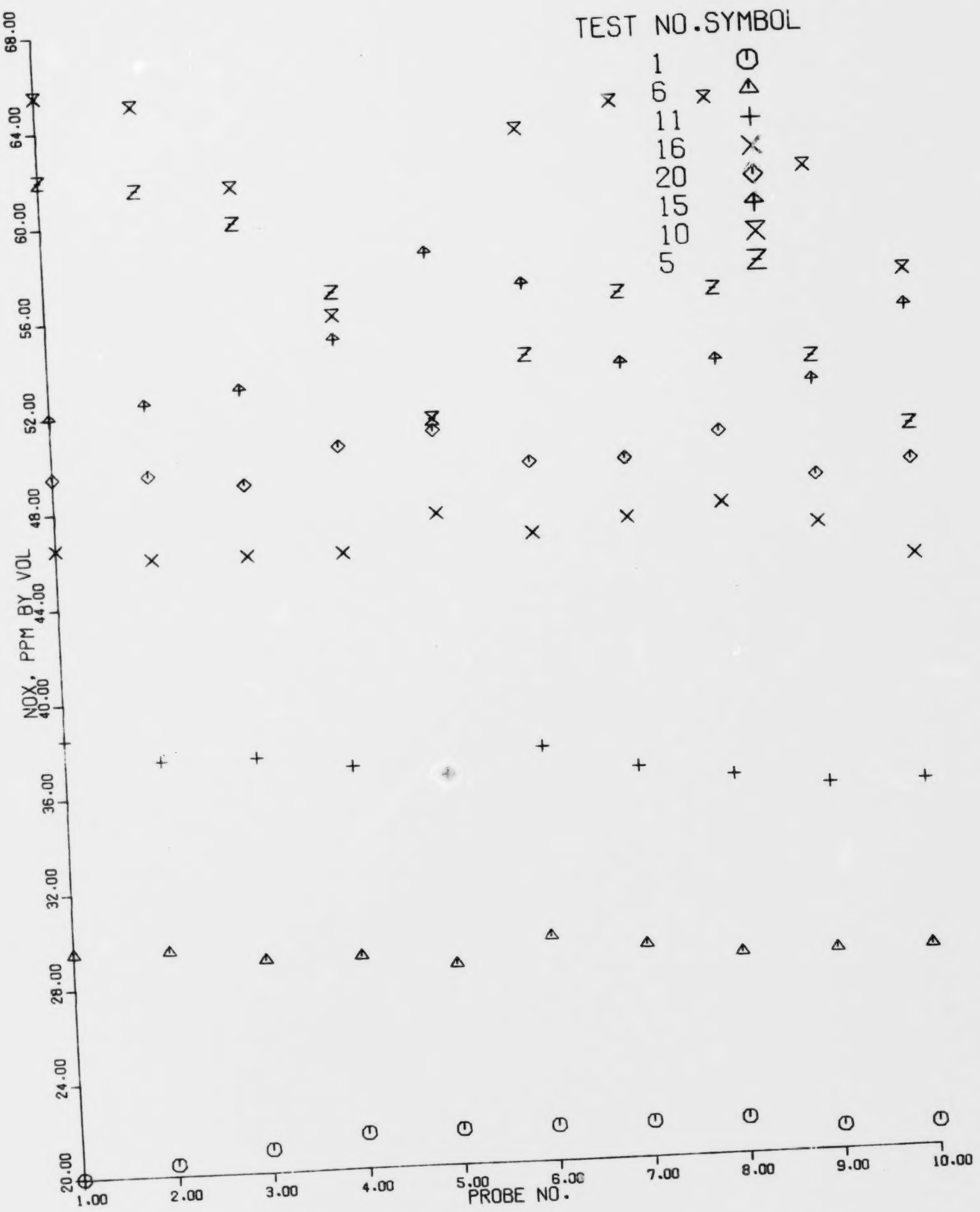

GTCP36-6, S/N P-34772, O/H, FUEL JP5 DATE 5/14/71 CELL D-115

GROUP 3

MEDIUM-SIZE AUXILIARY POWER UNITS

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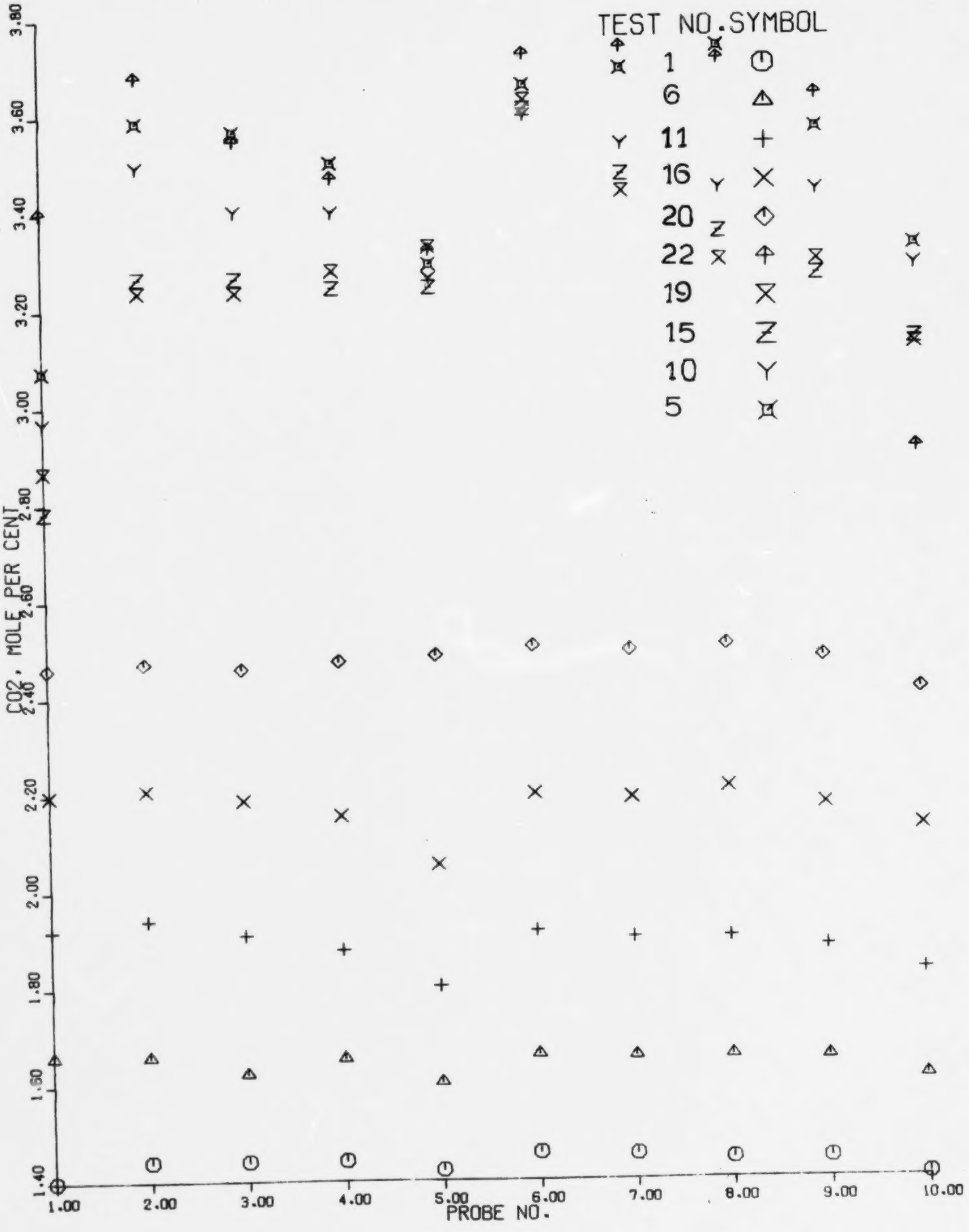
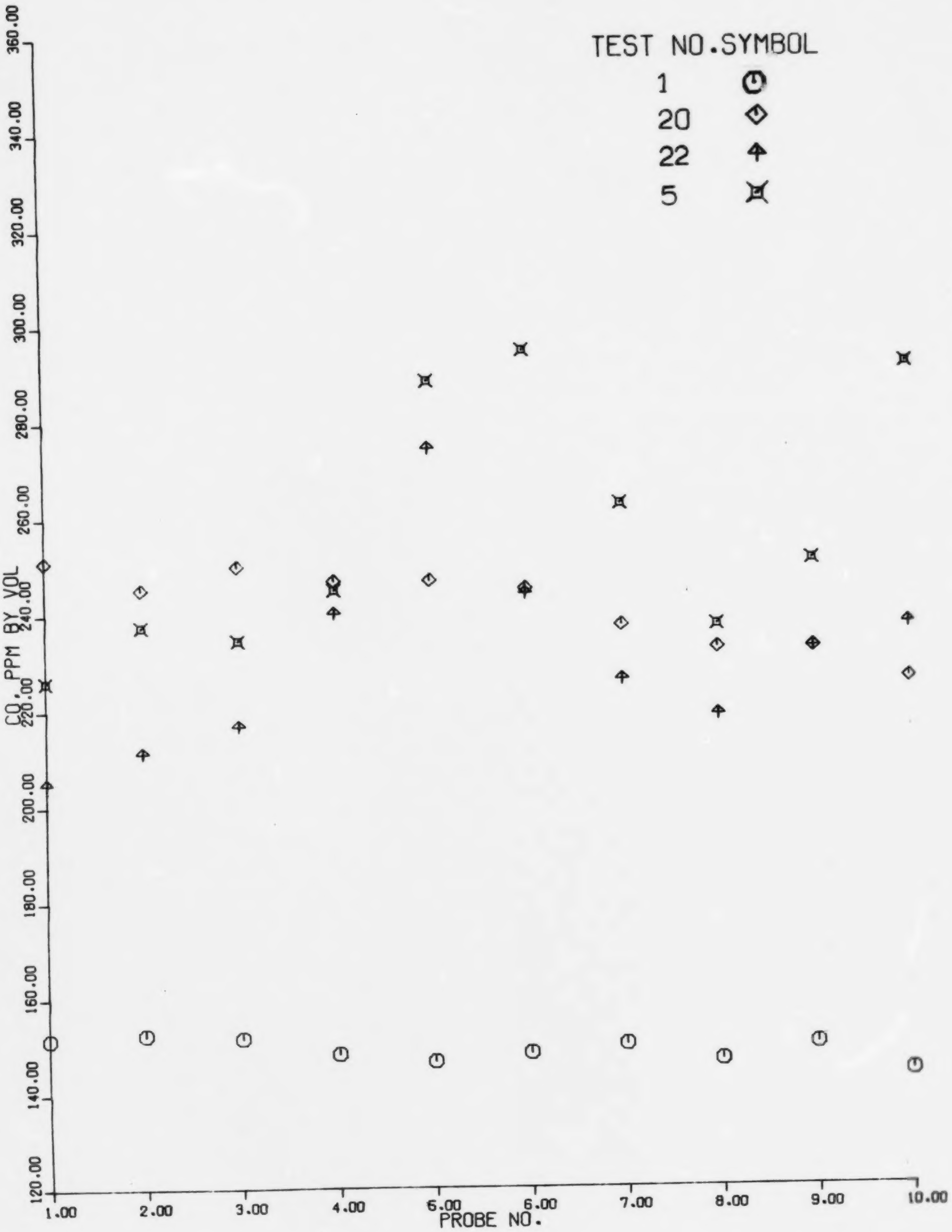


GTCP85-180(98CK) S/N P-567 PROD. FUEL AV.KEROS. DATE 6/14/71 CELL D-111



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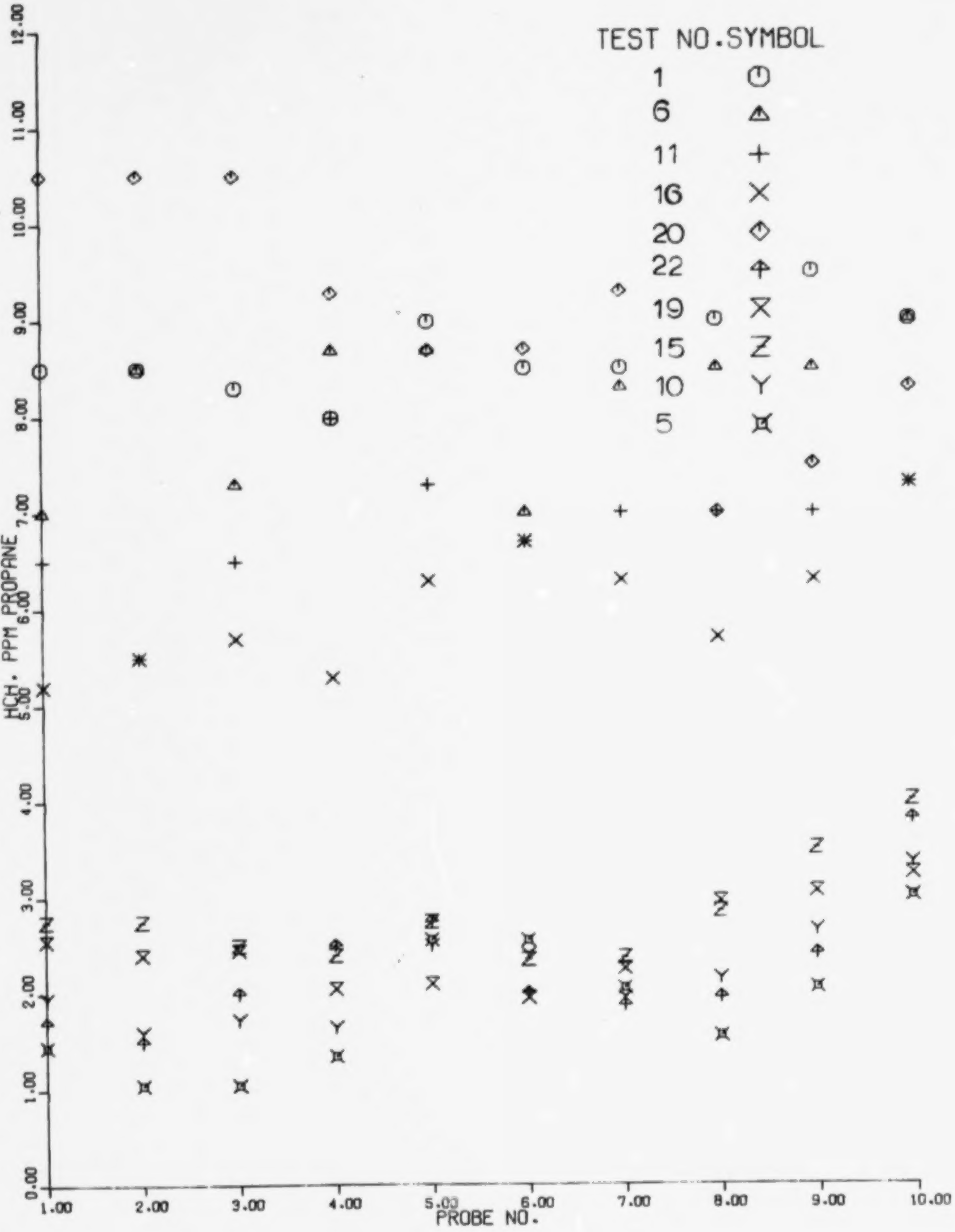

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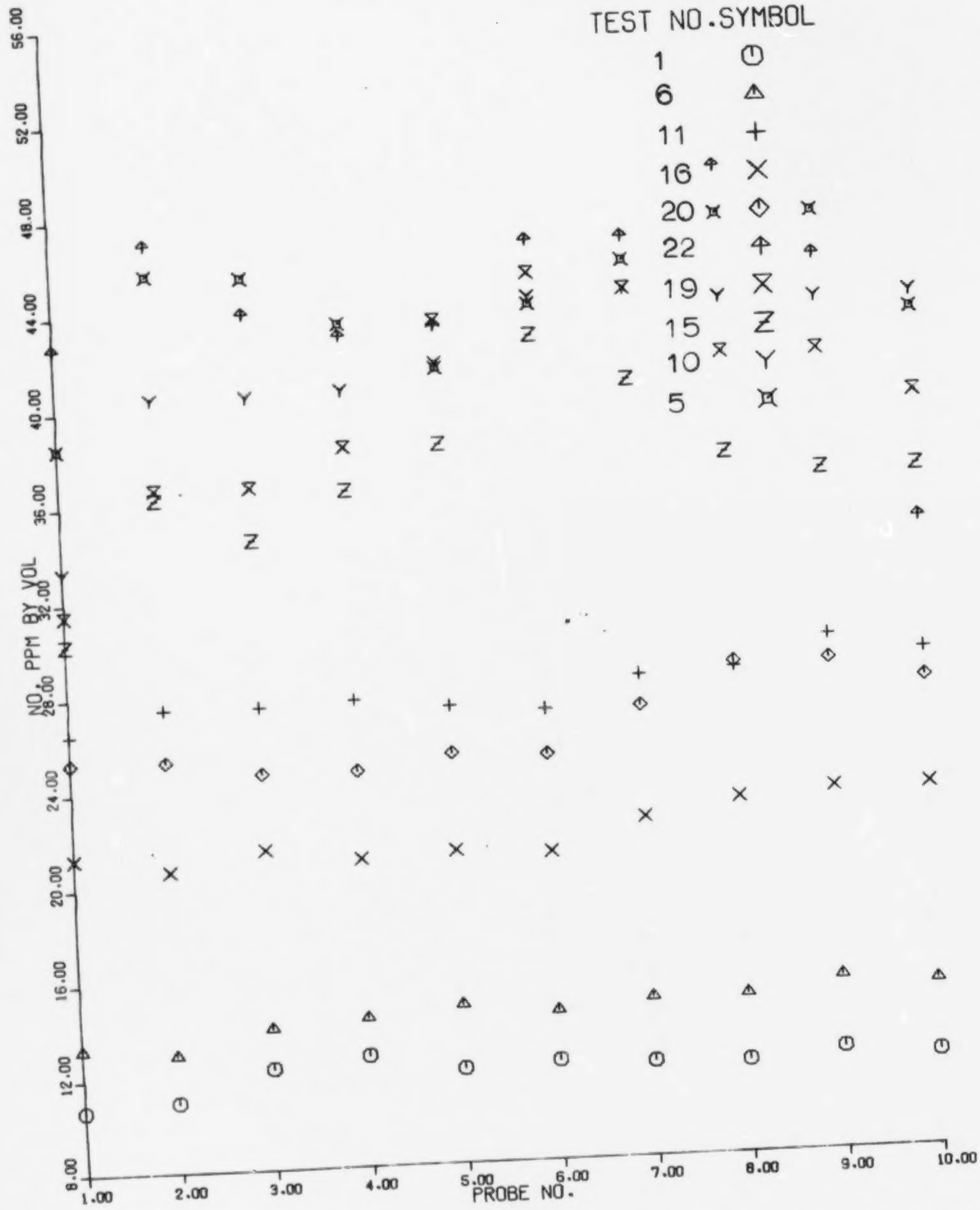

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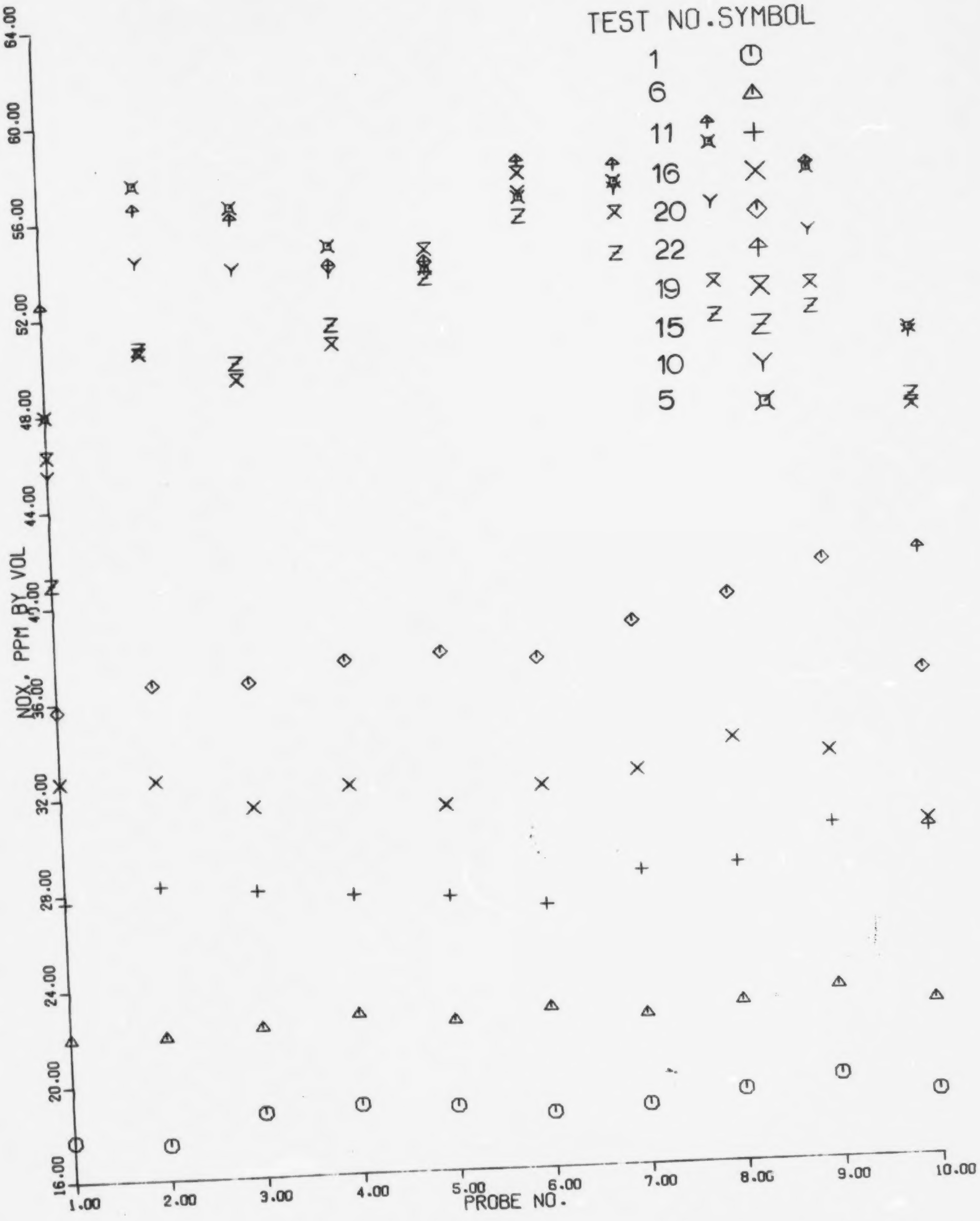

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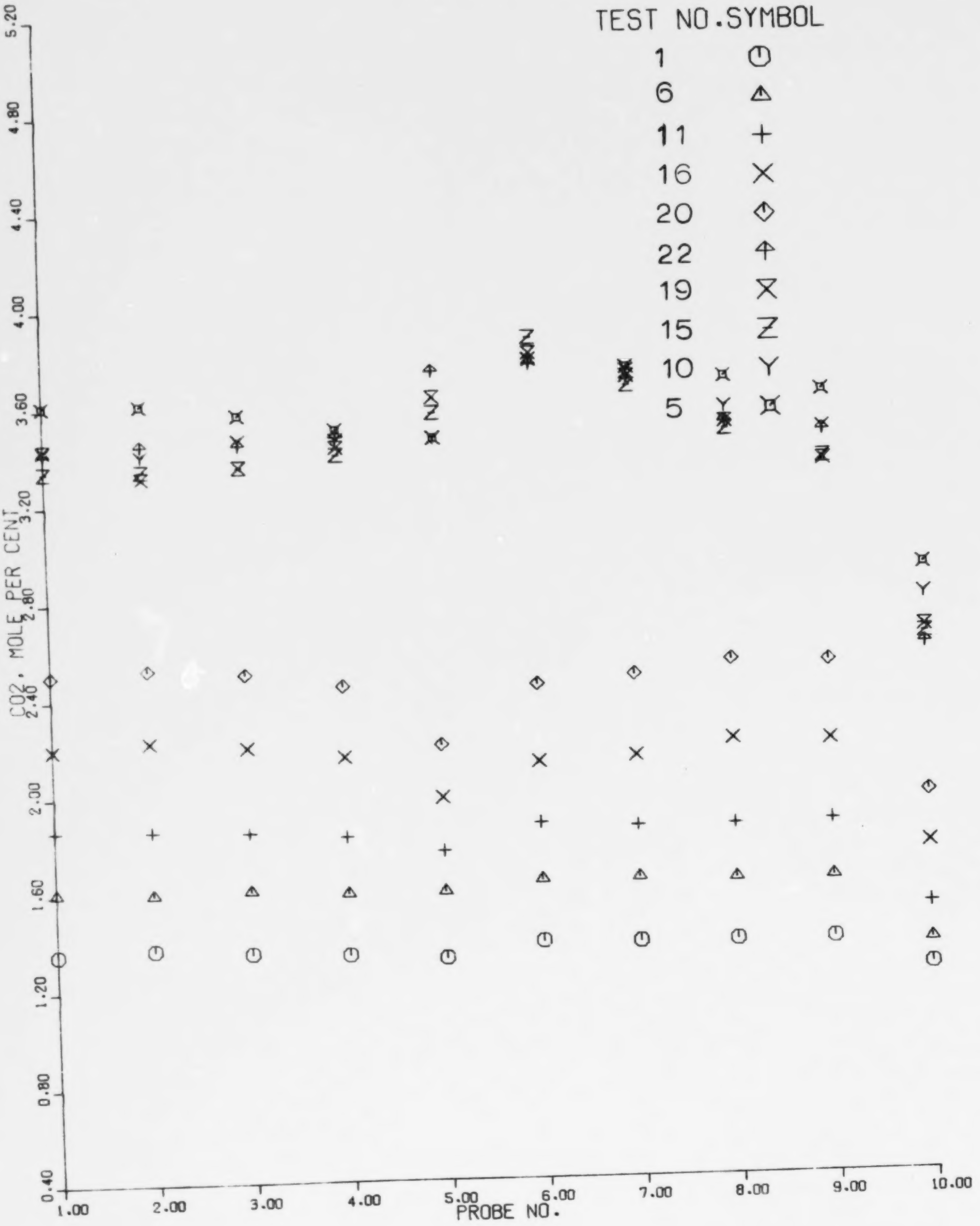

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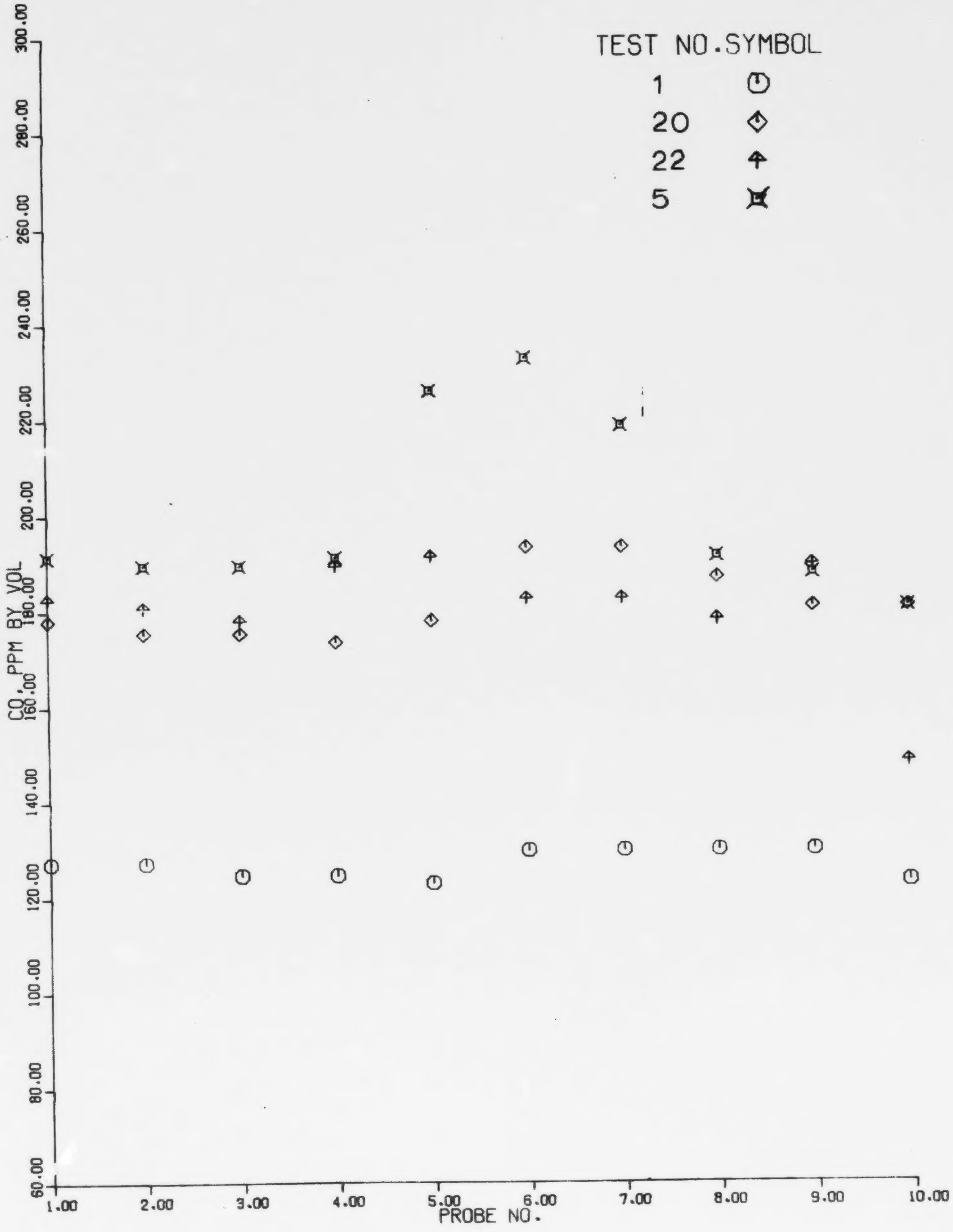

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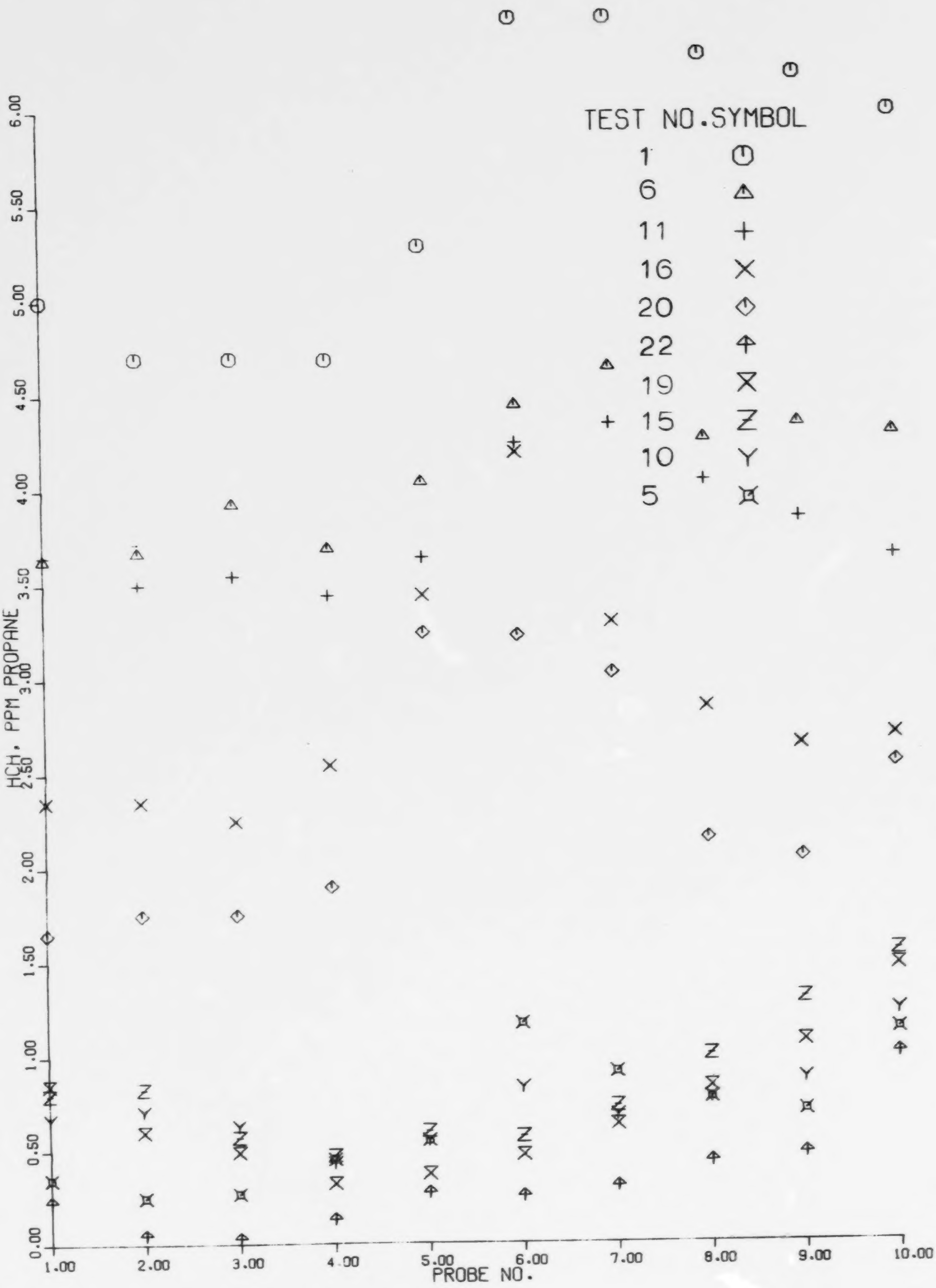

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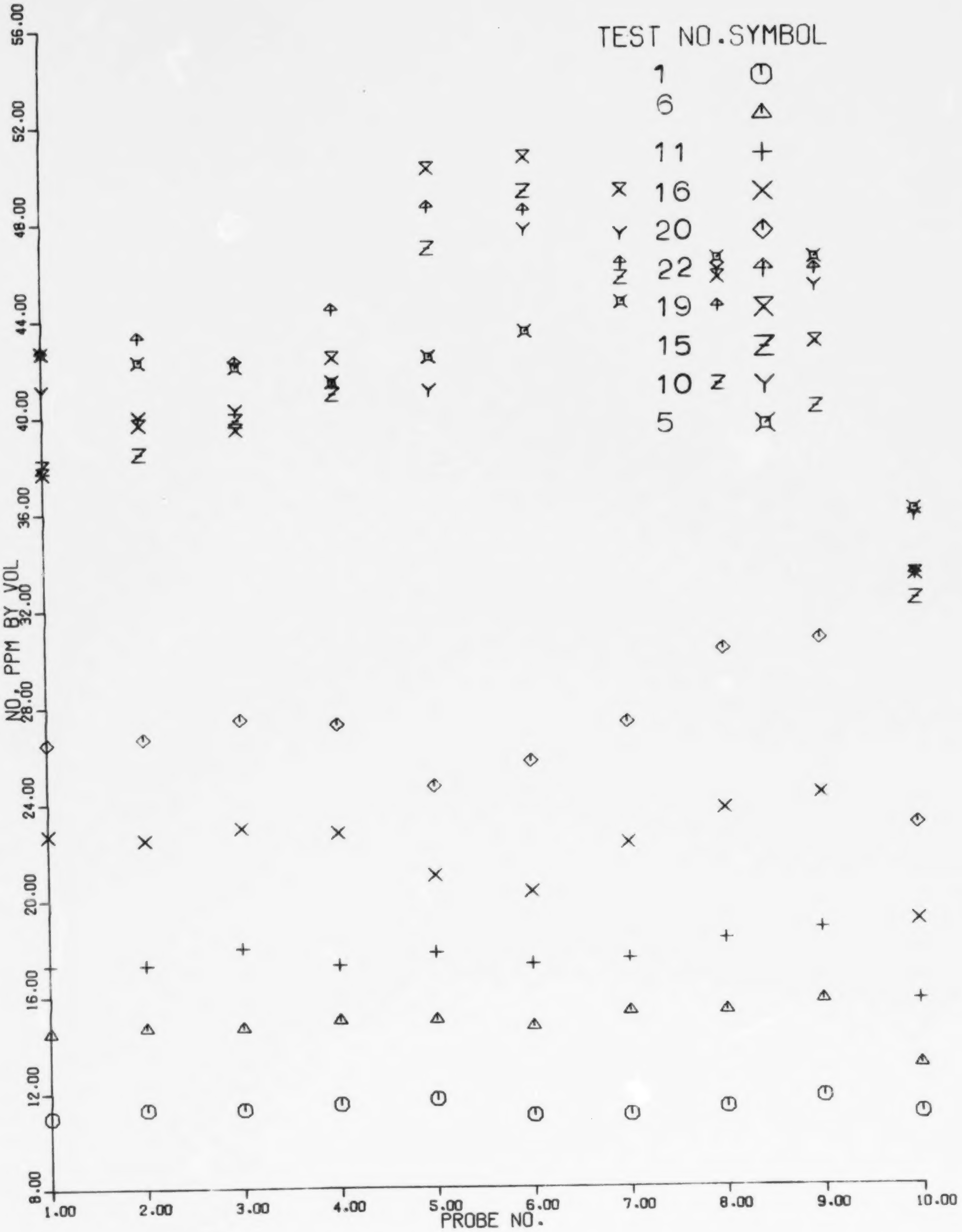

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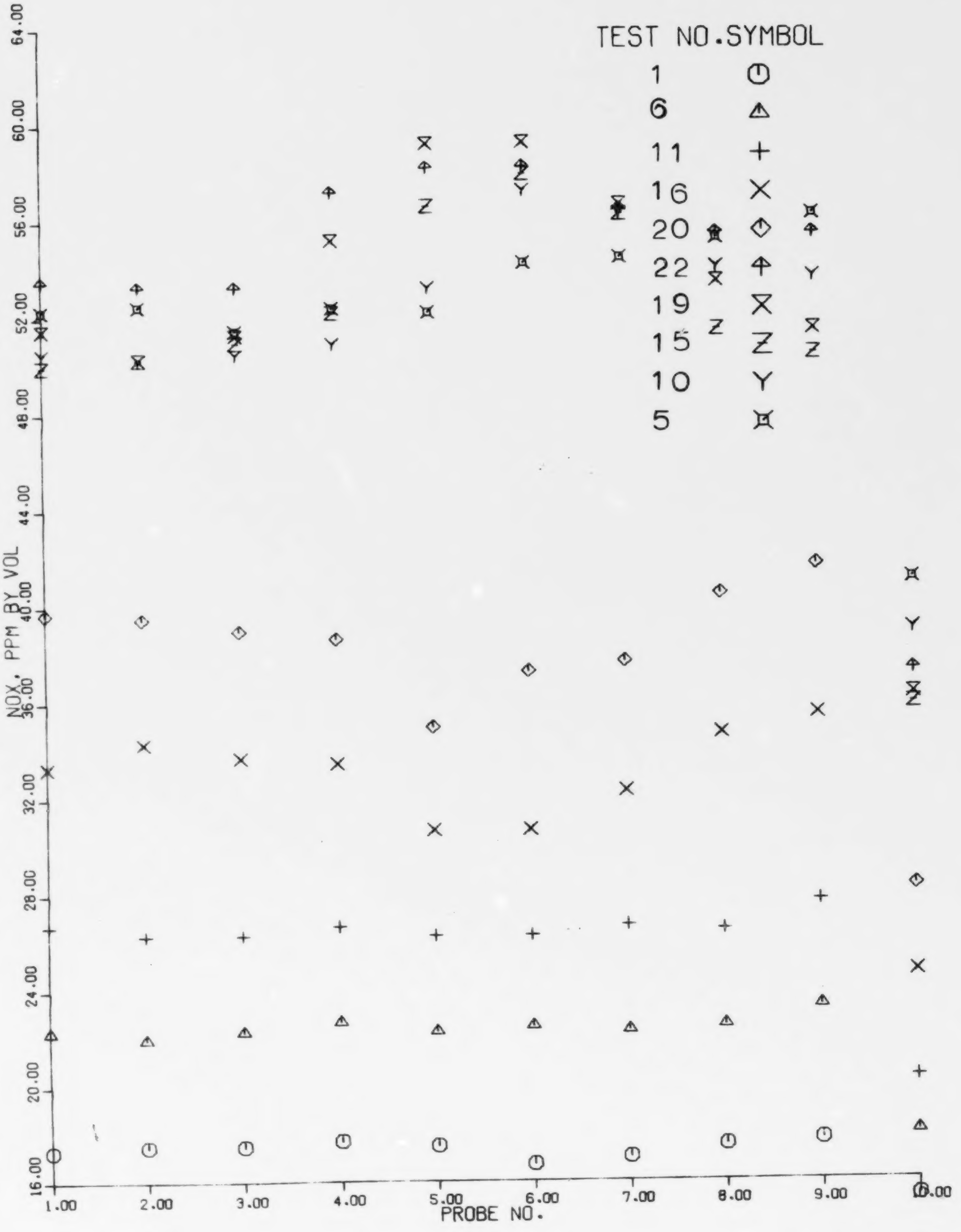

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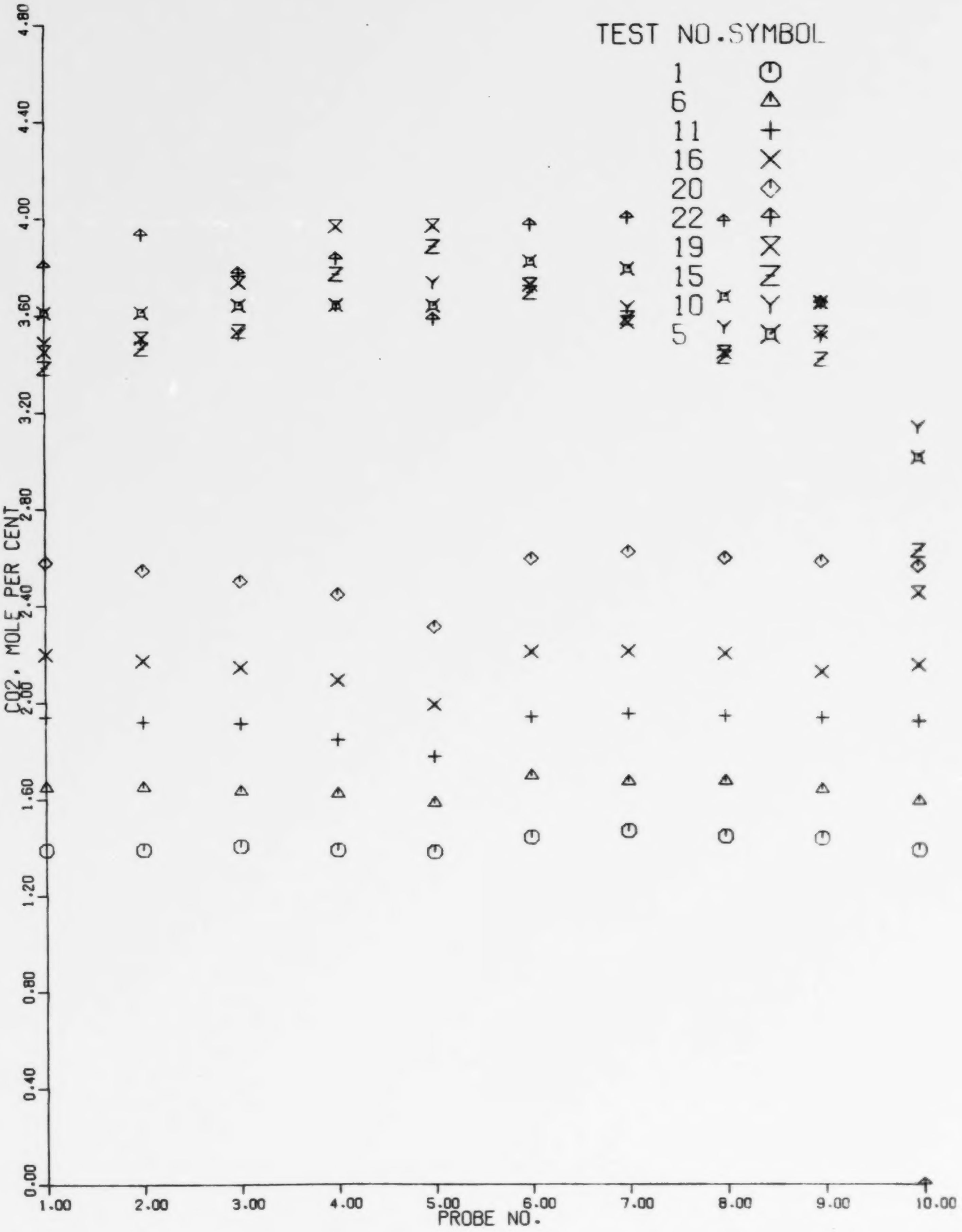

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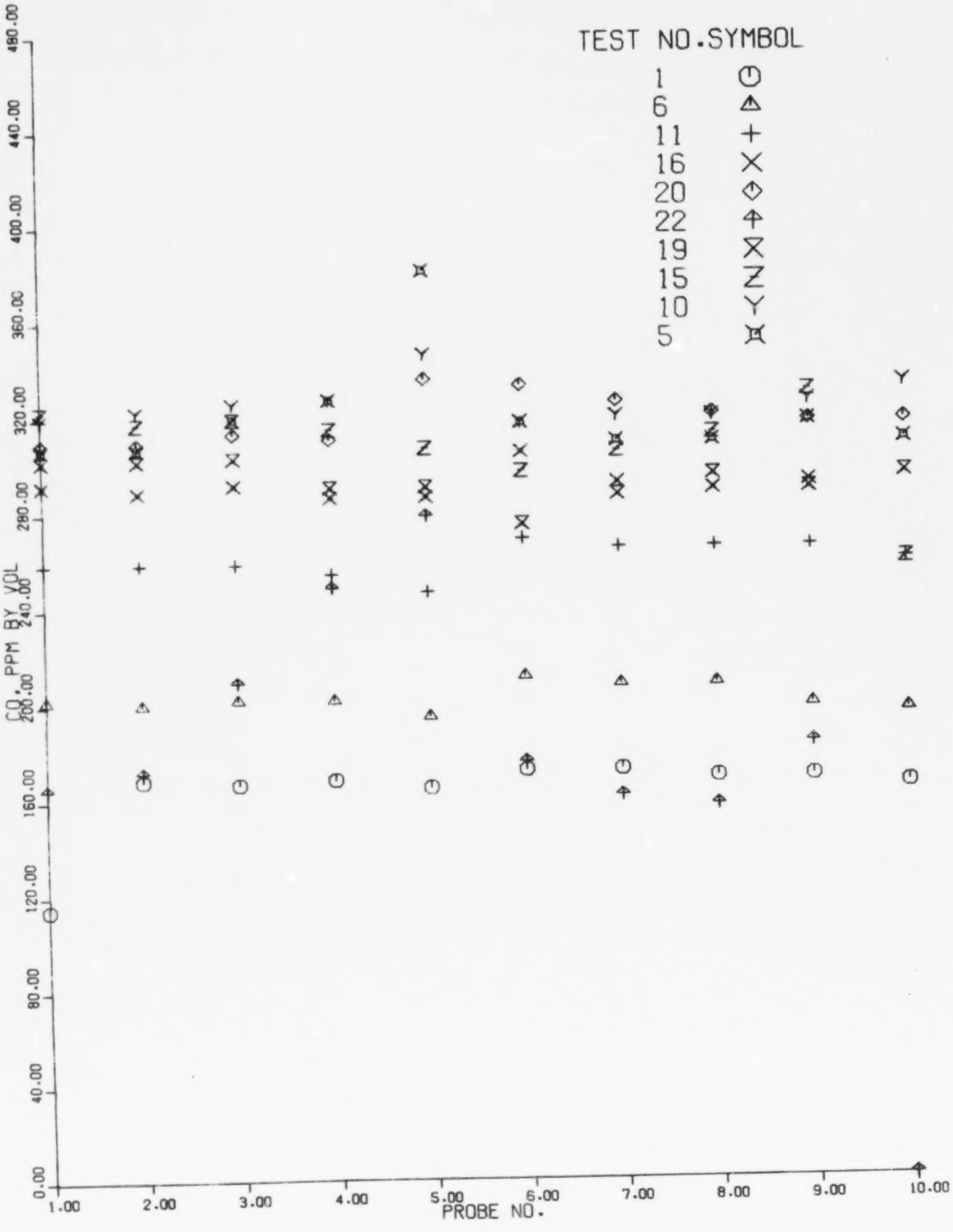

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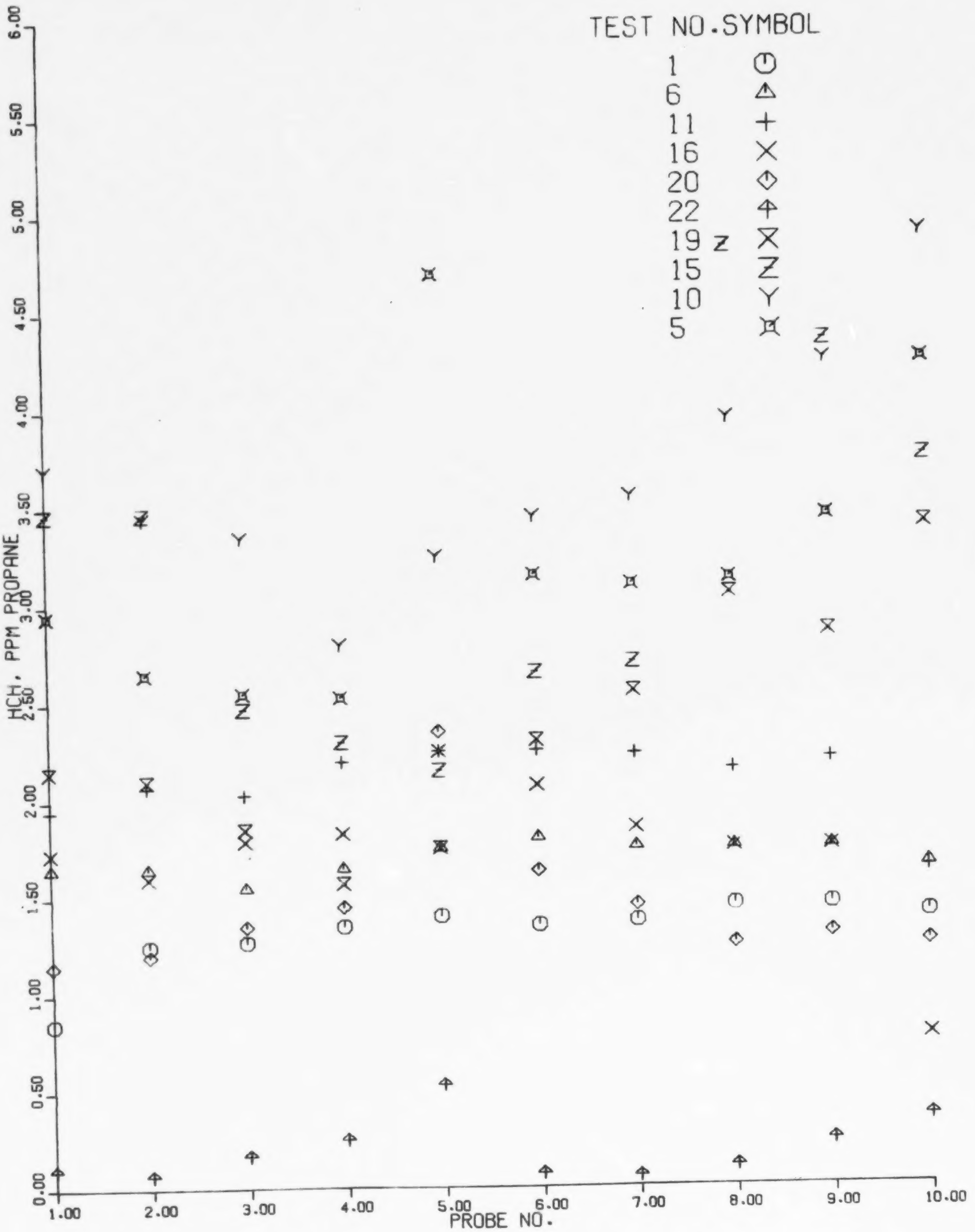

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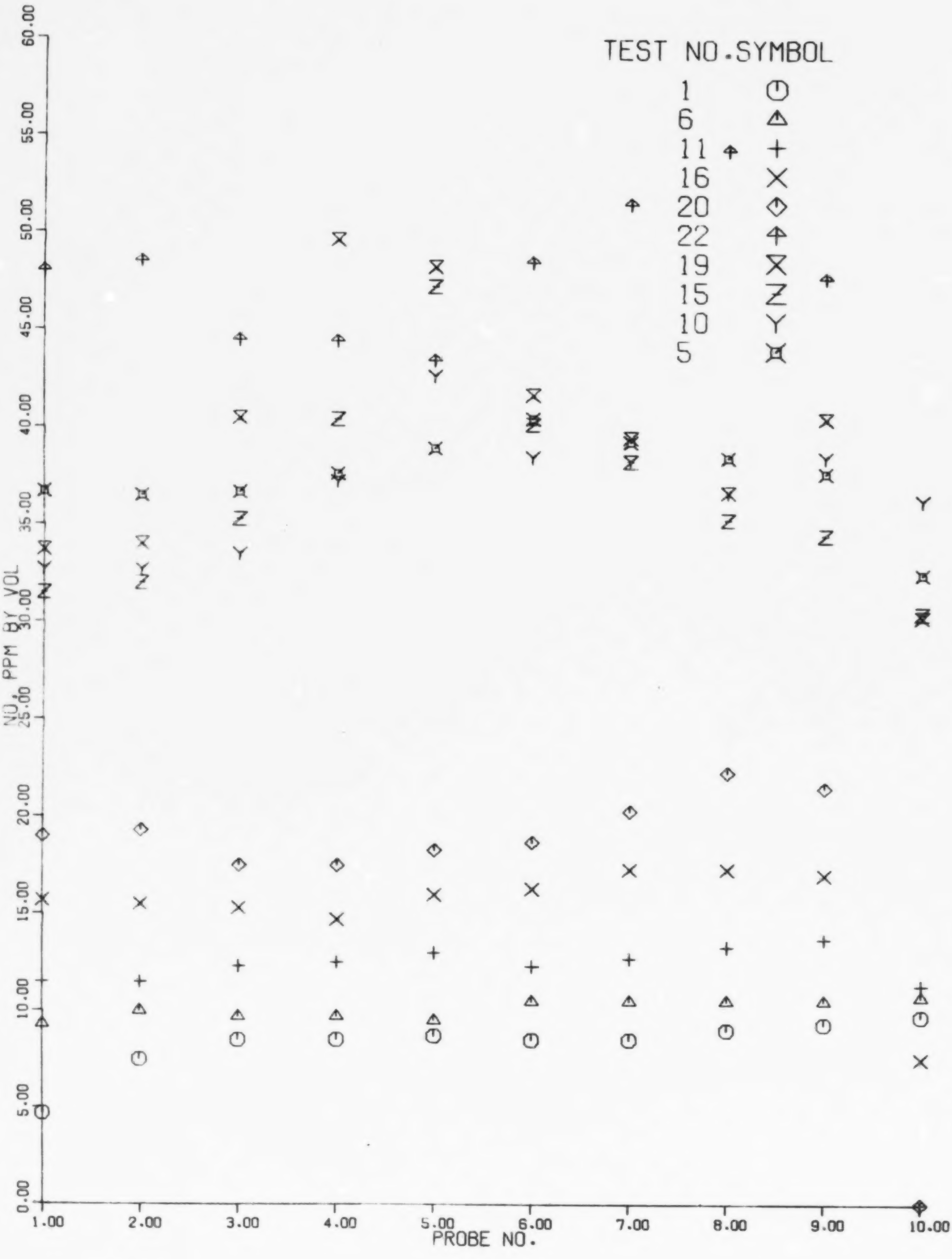

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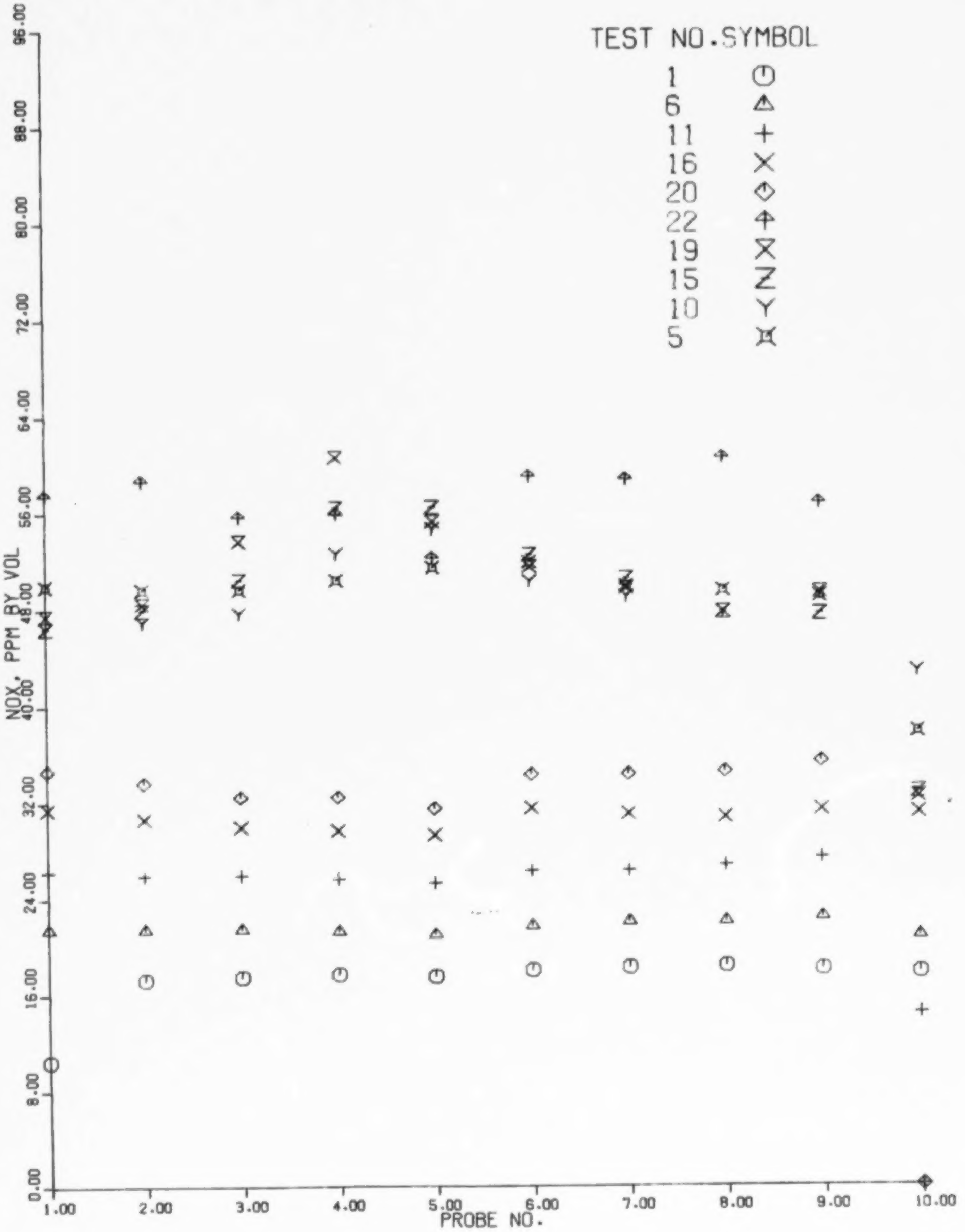

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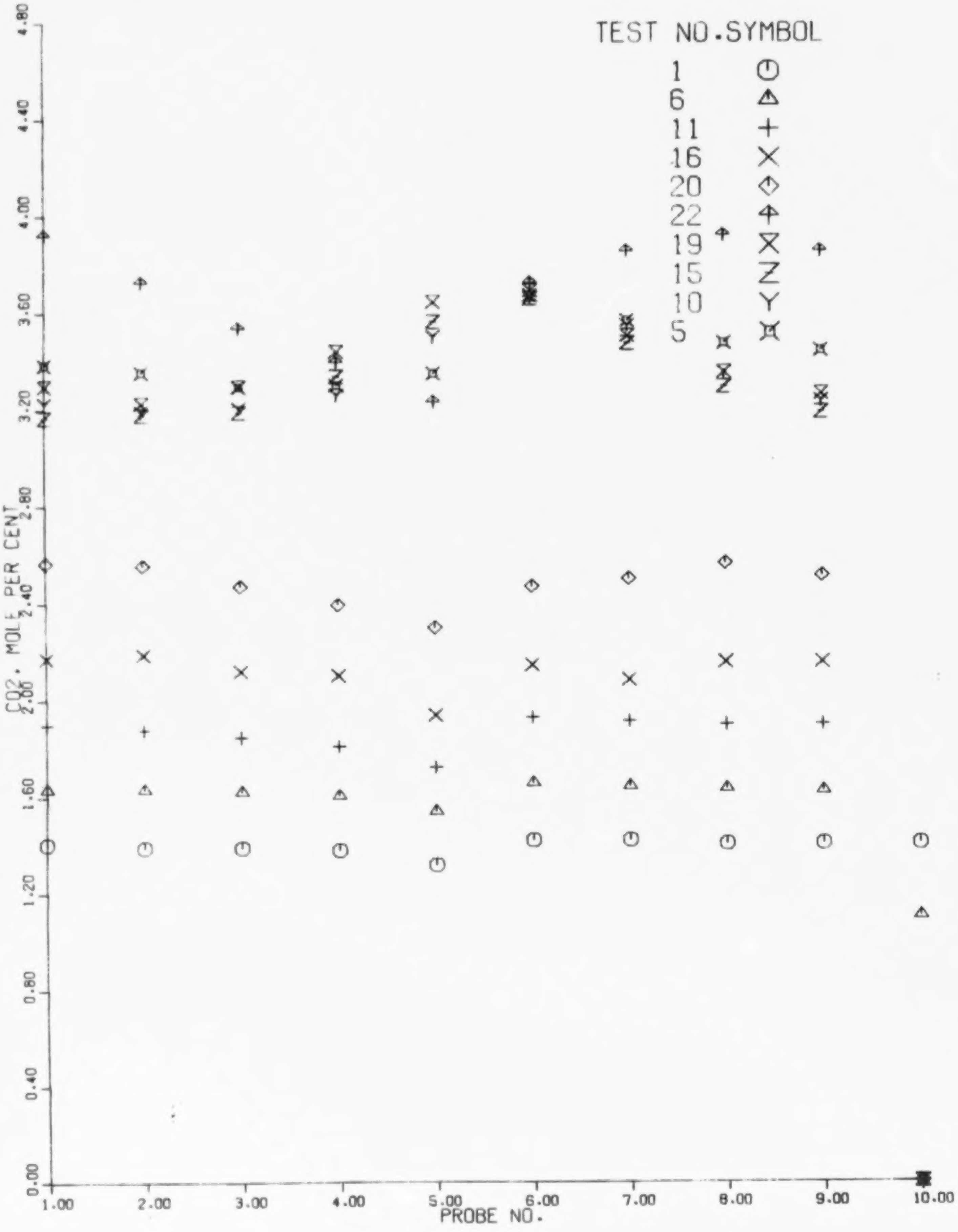

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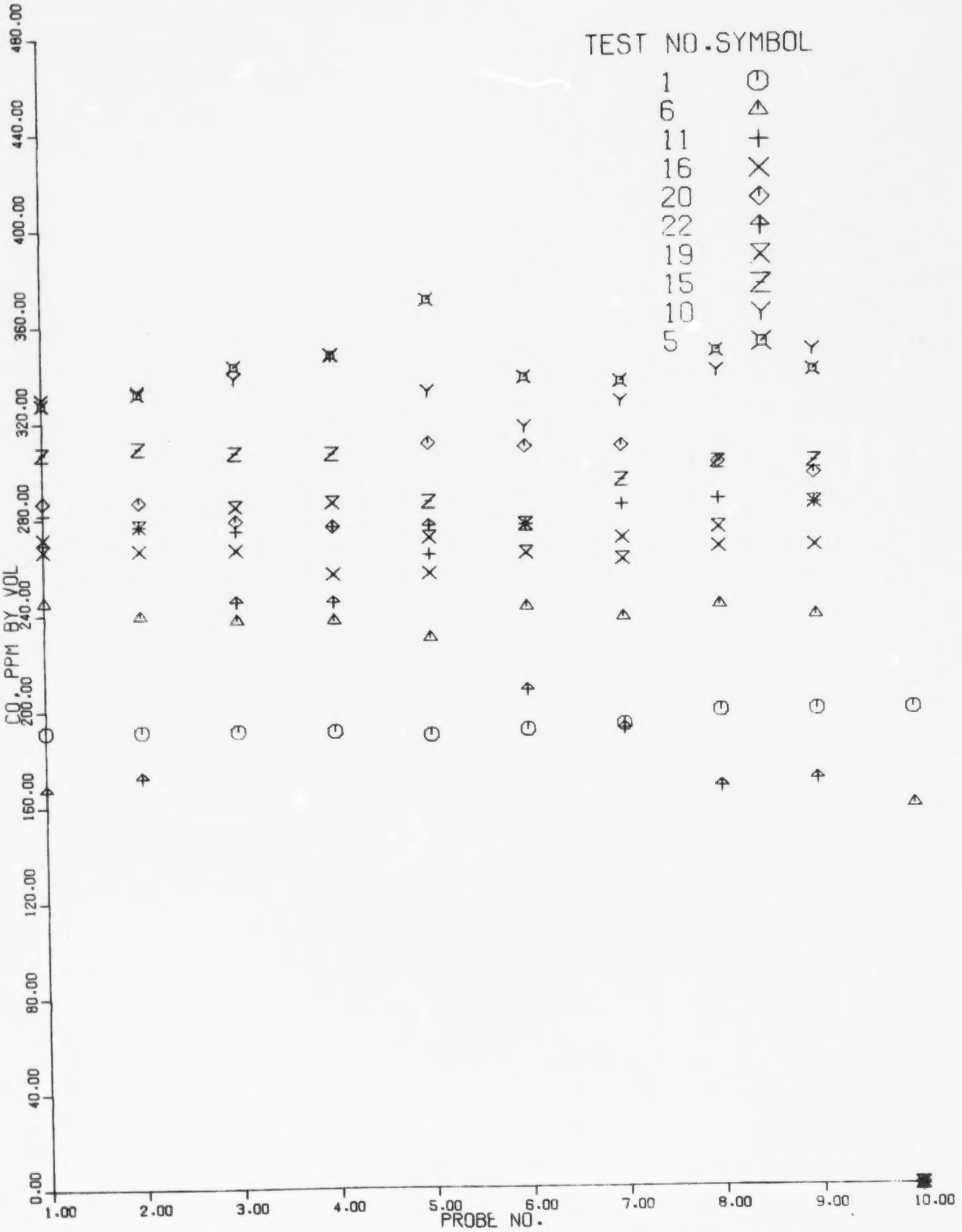

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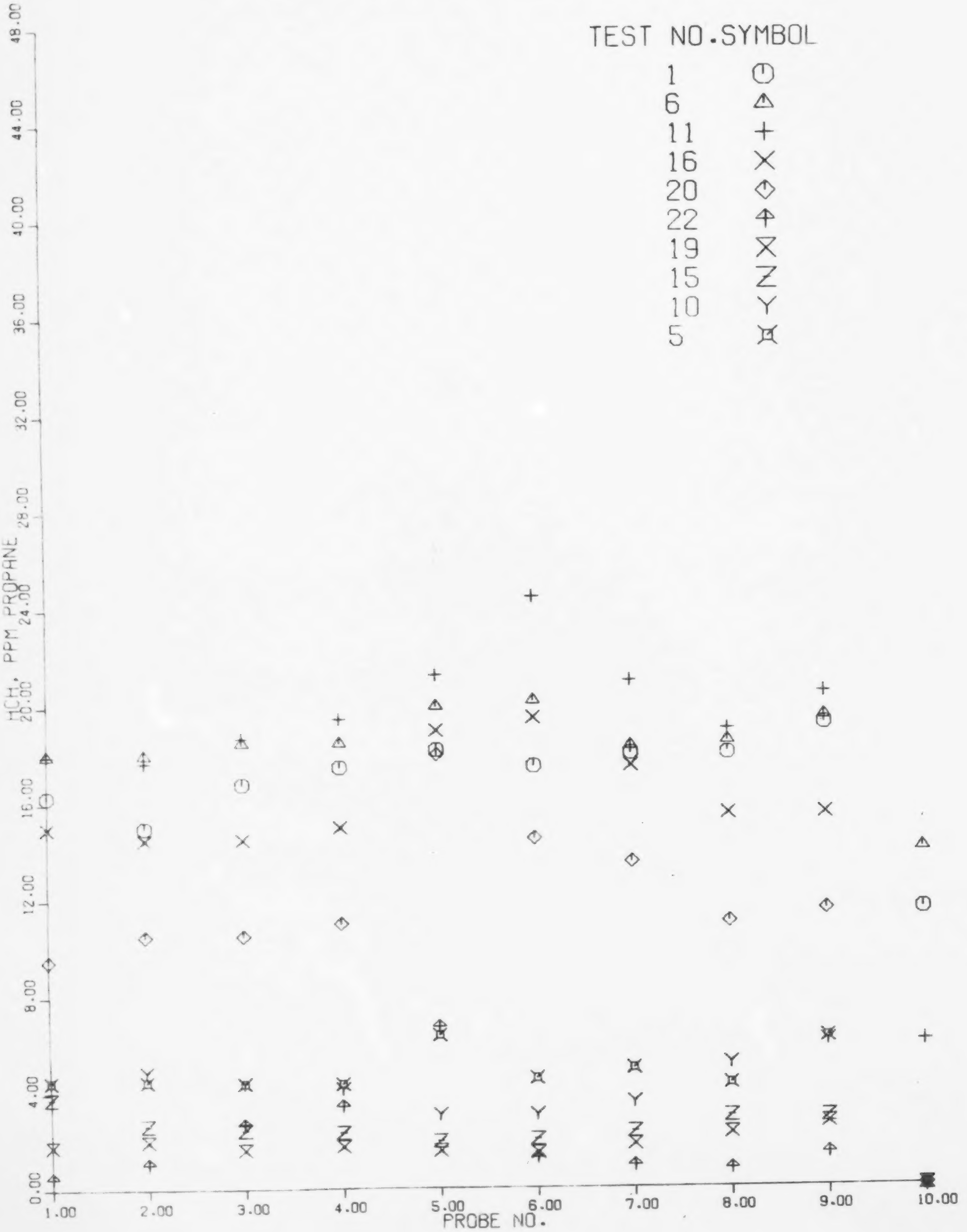

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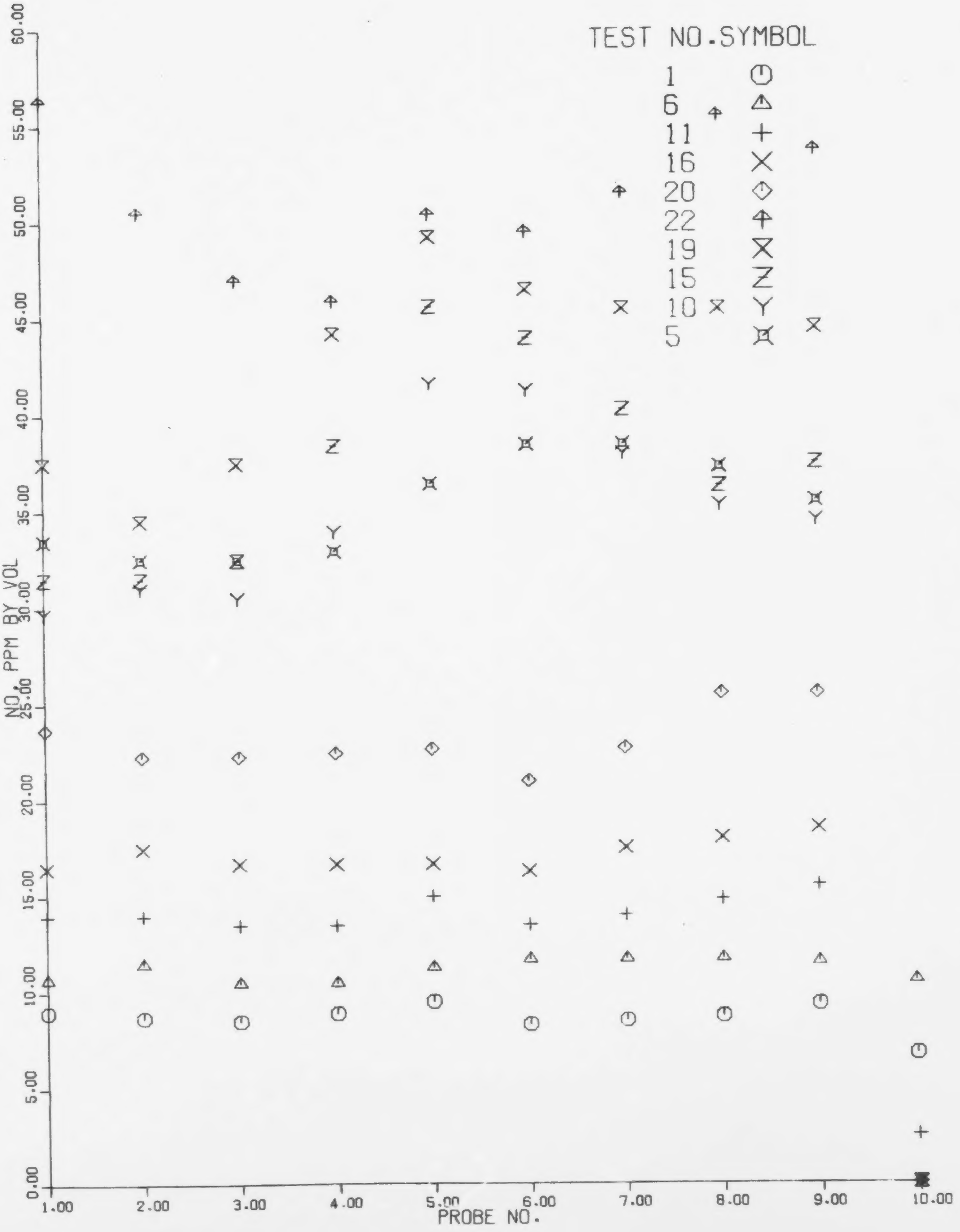

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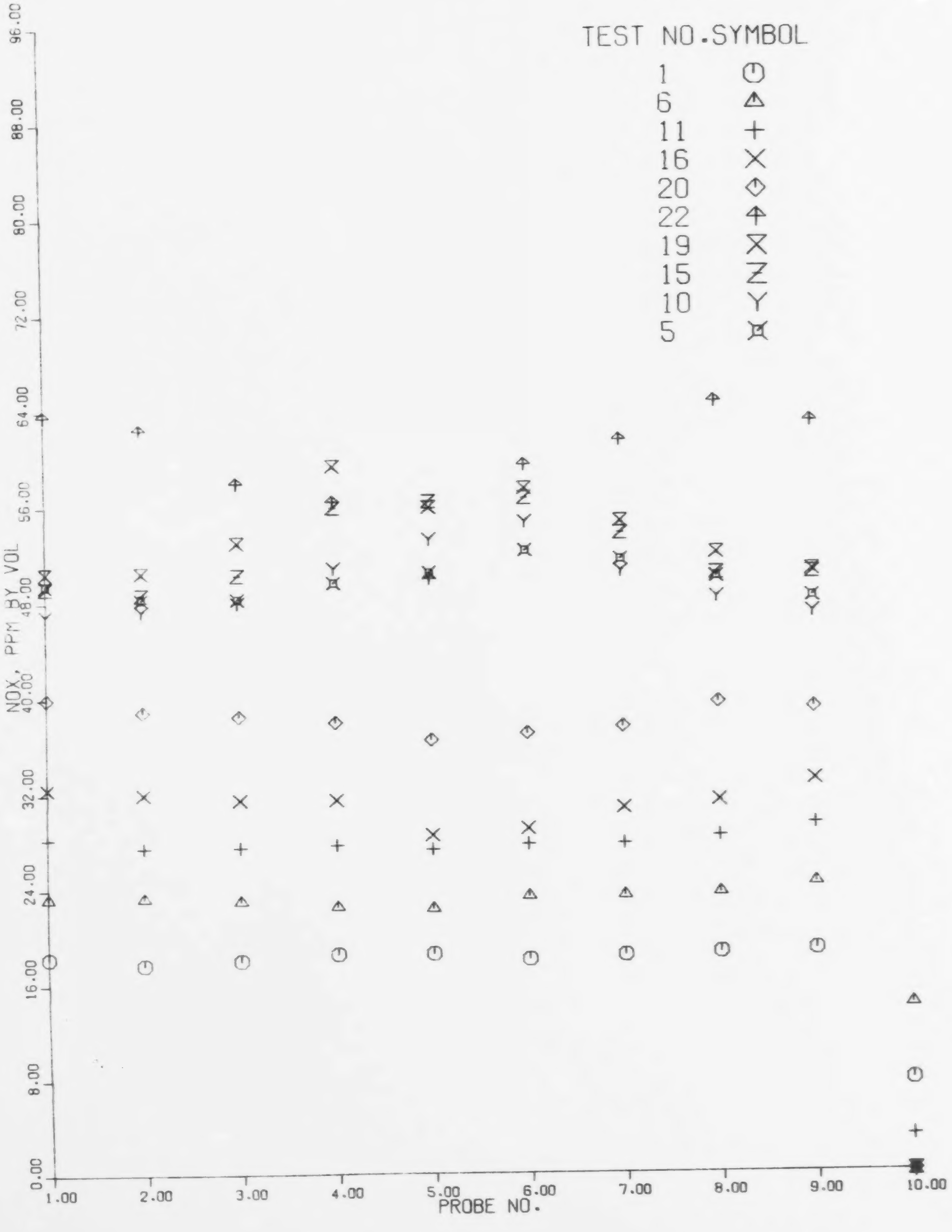

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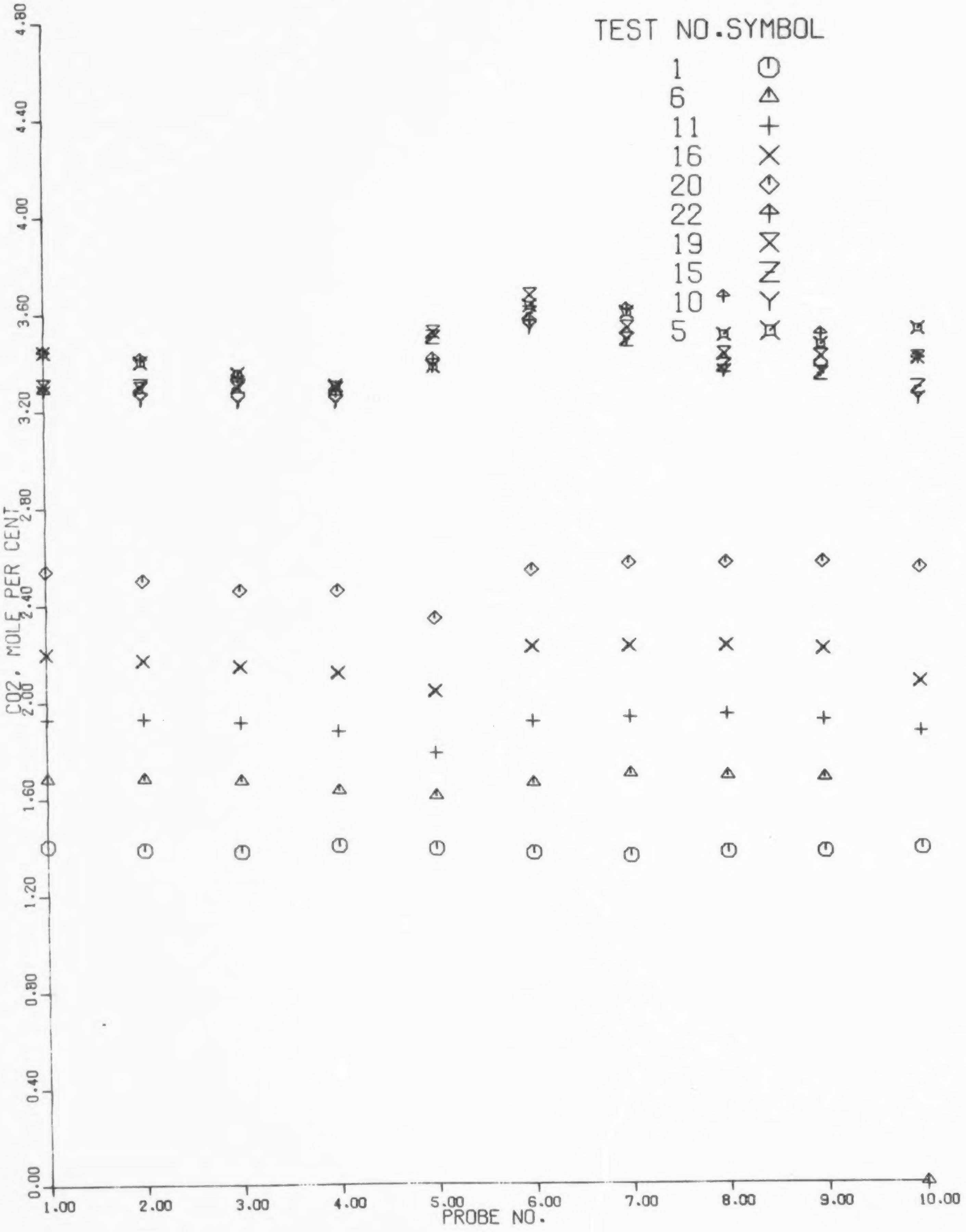

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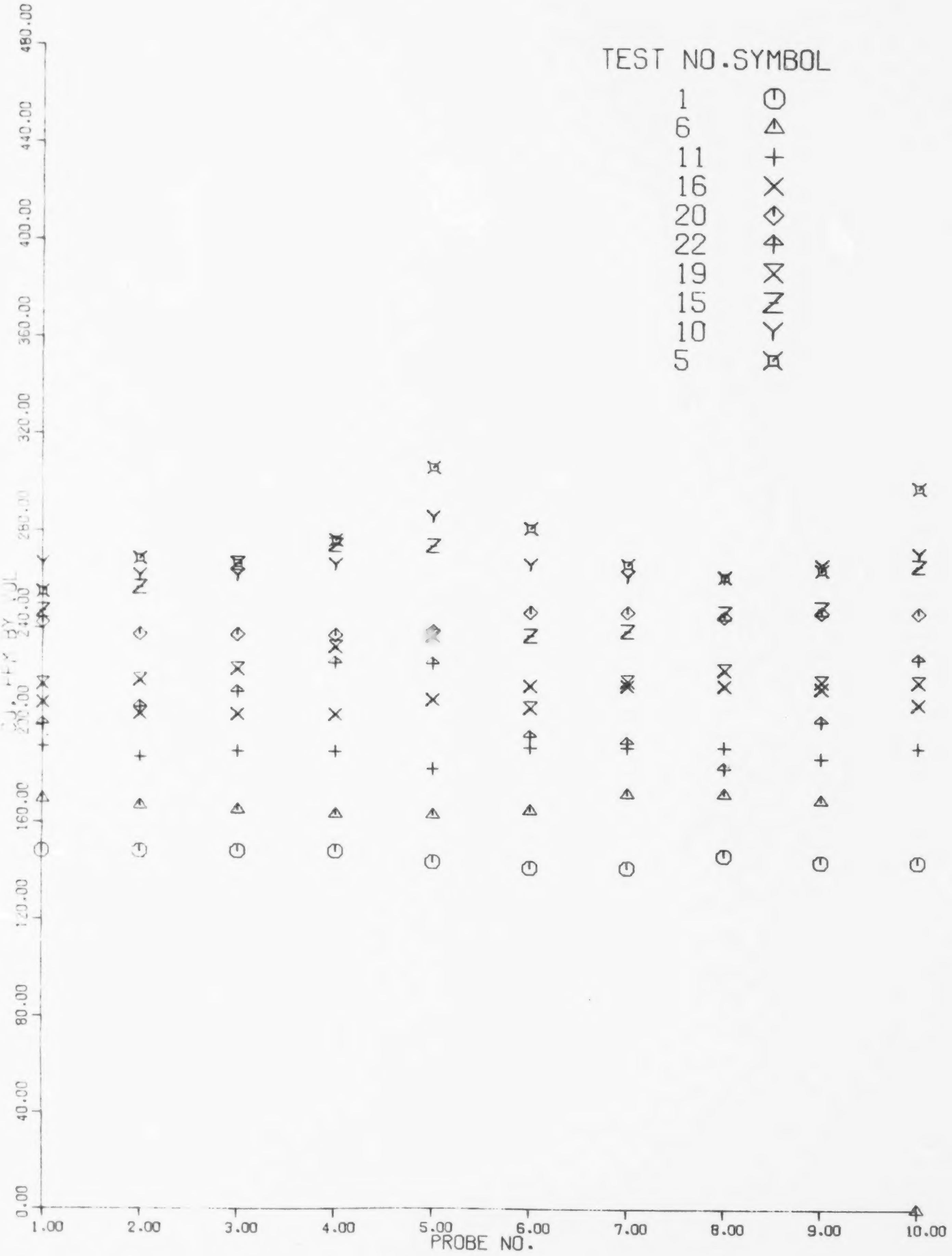

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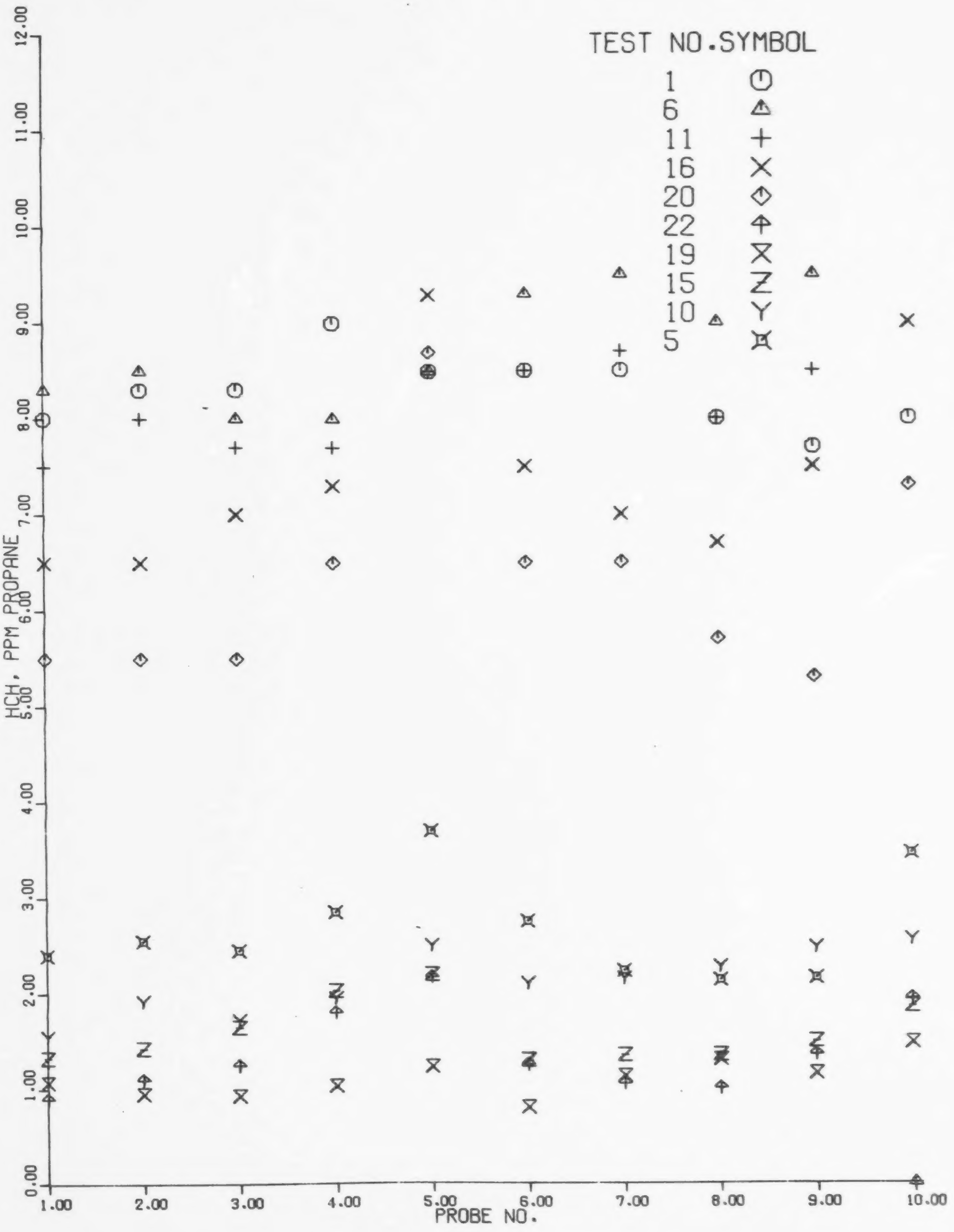

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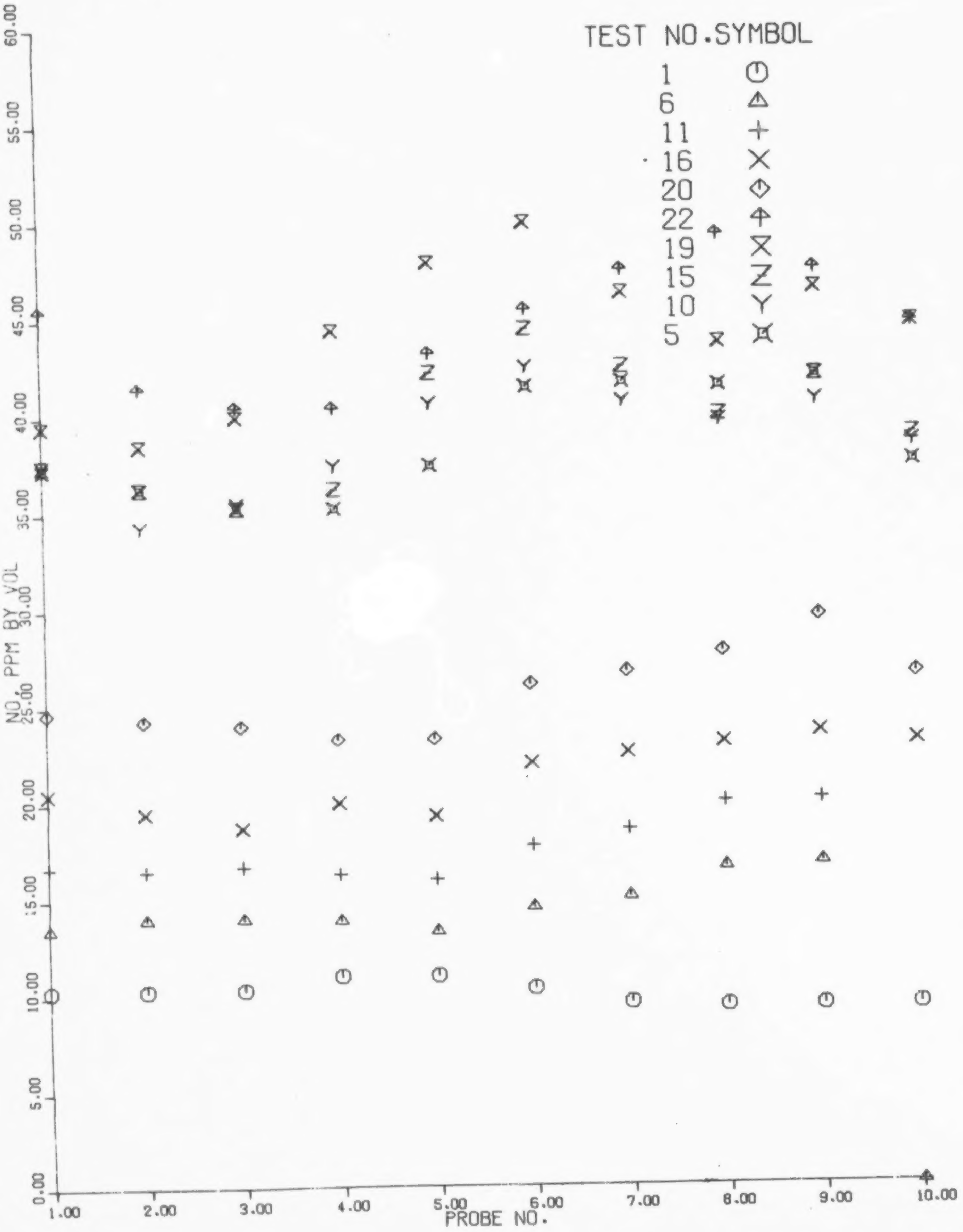

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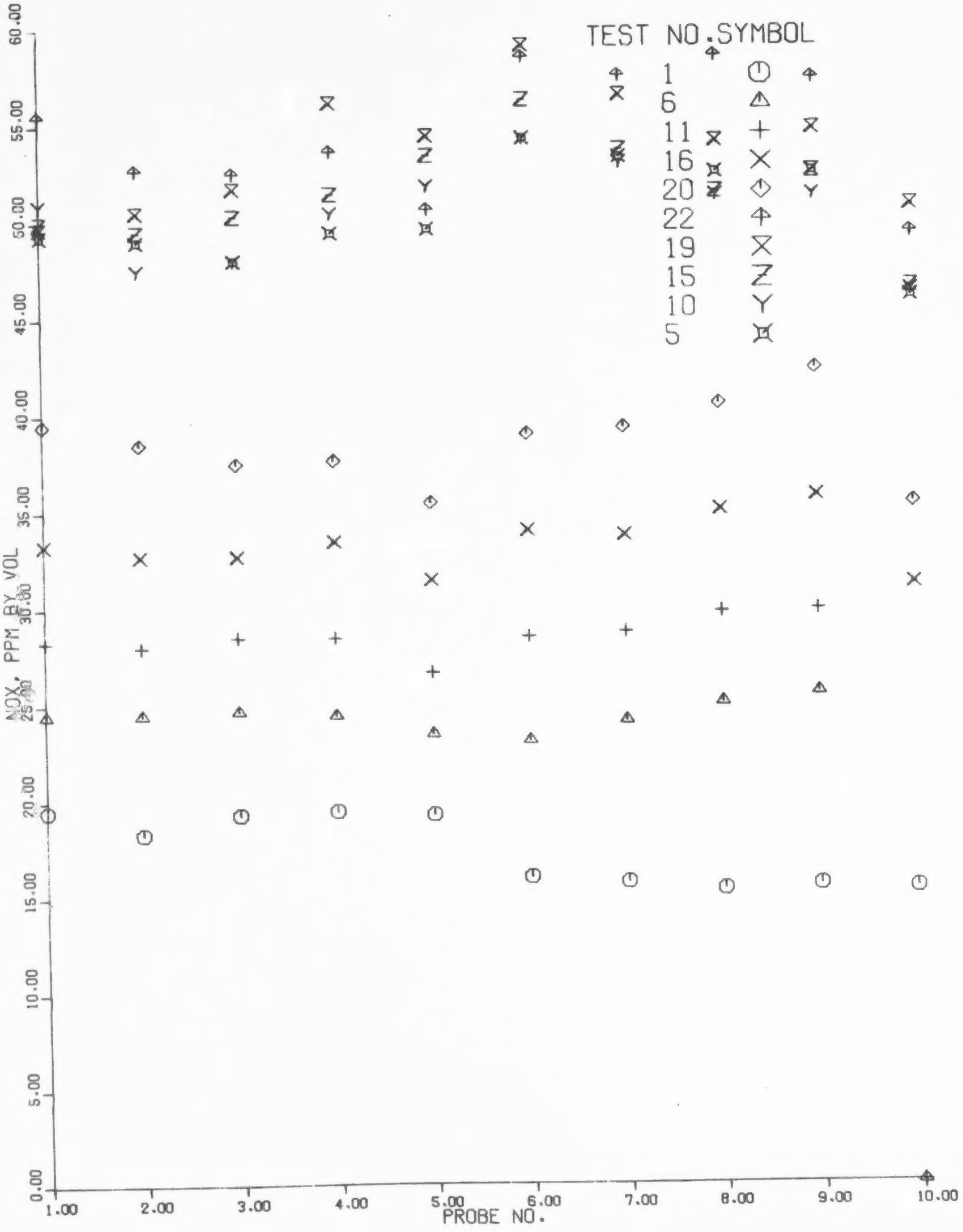
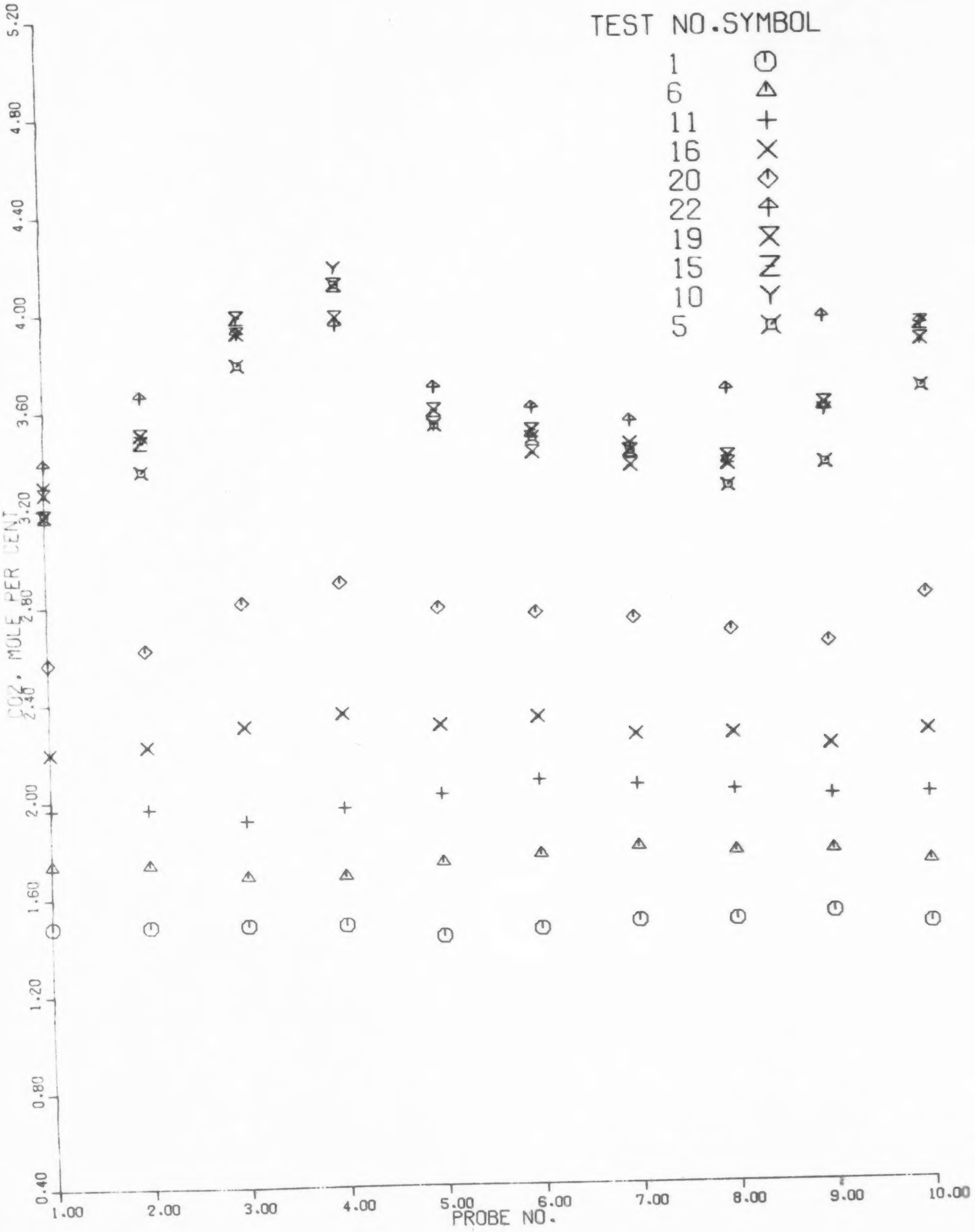


GTCP85-180 P-593 PROD. FUEL AVK. DATE 6/16/71 CELL D-111



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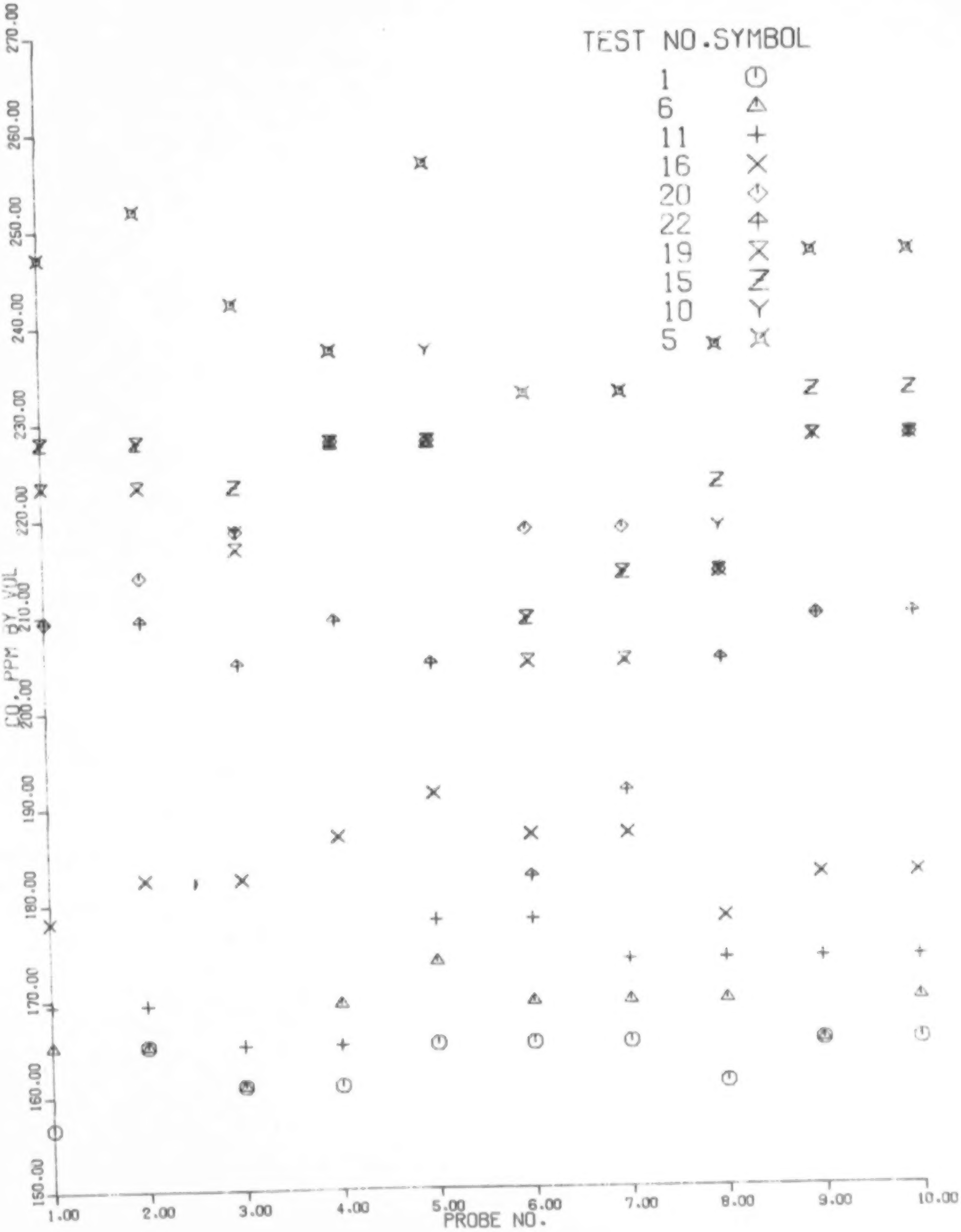

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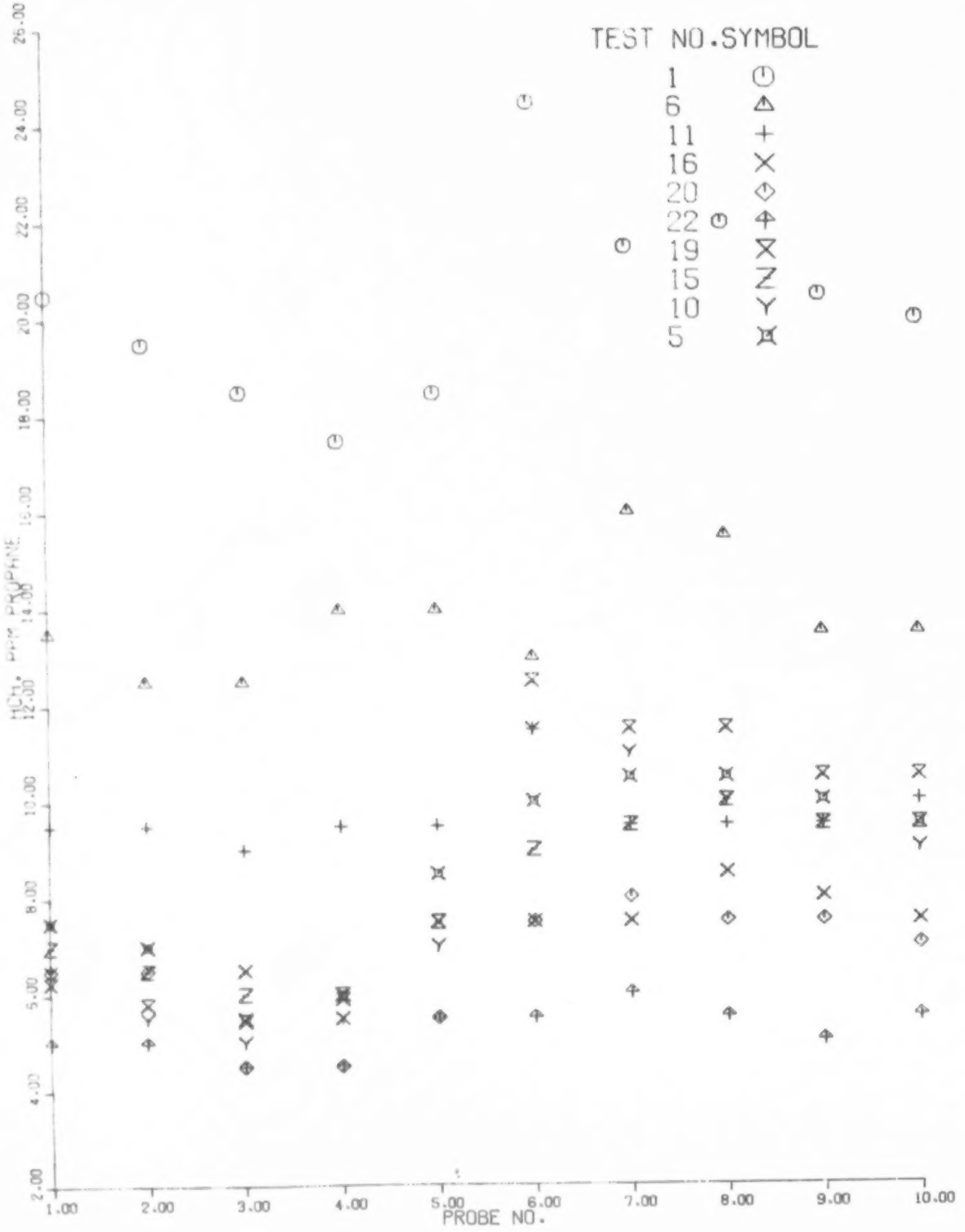

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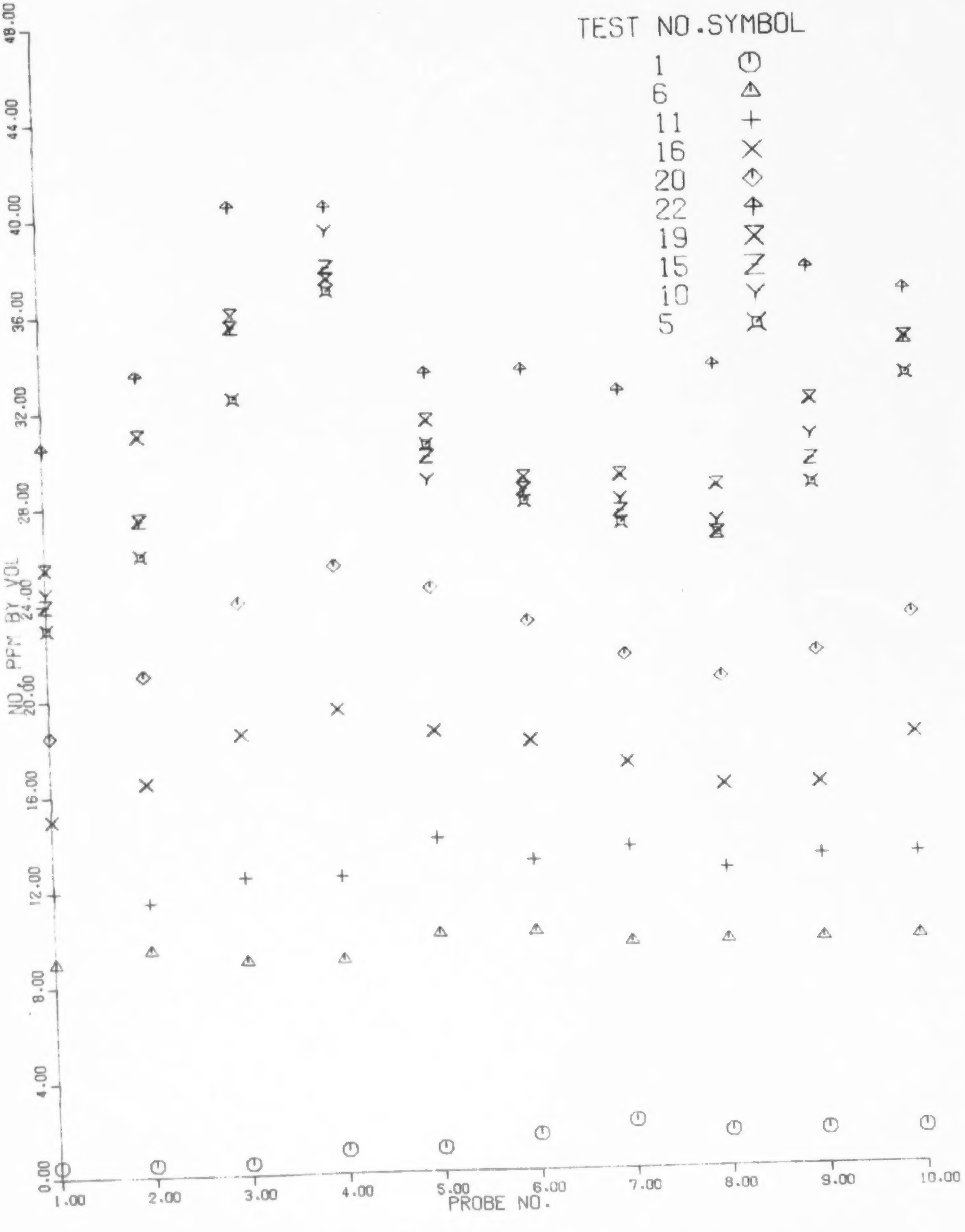

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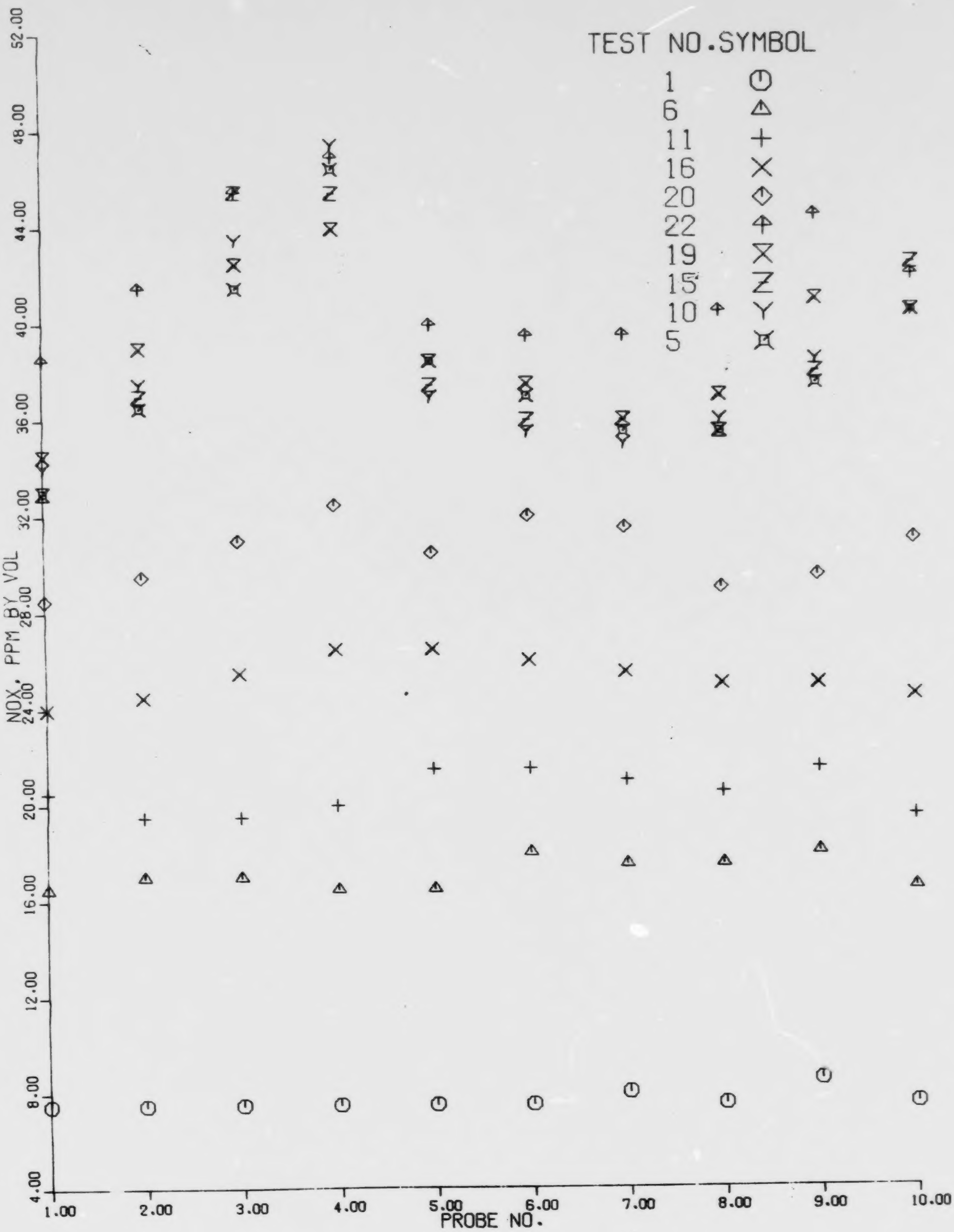

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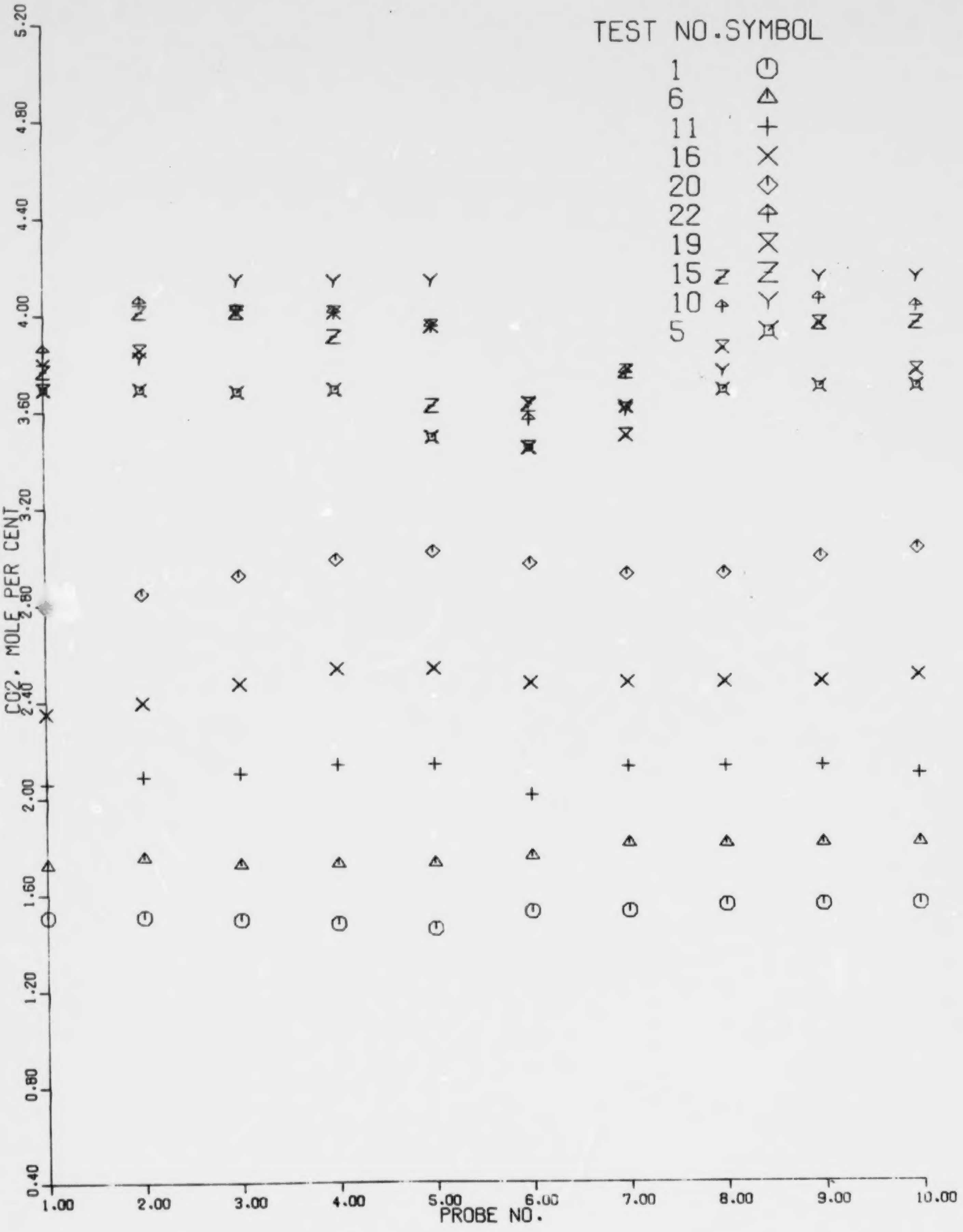

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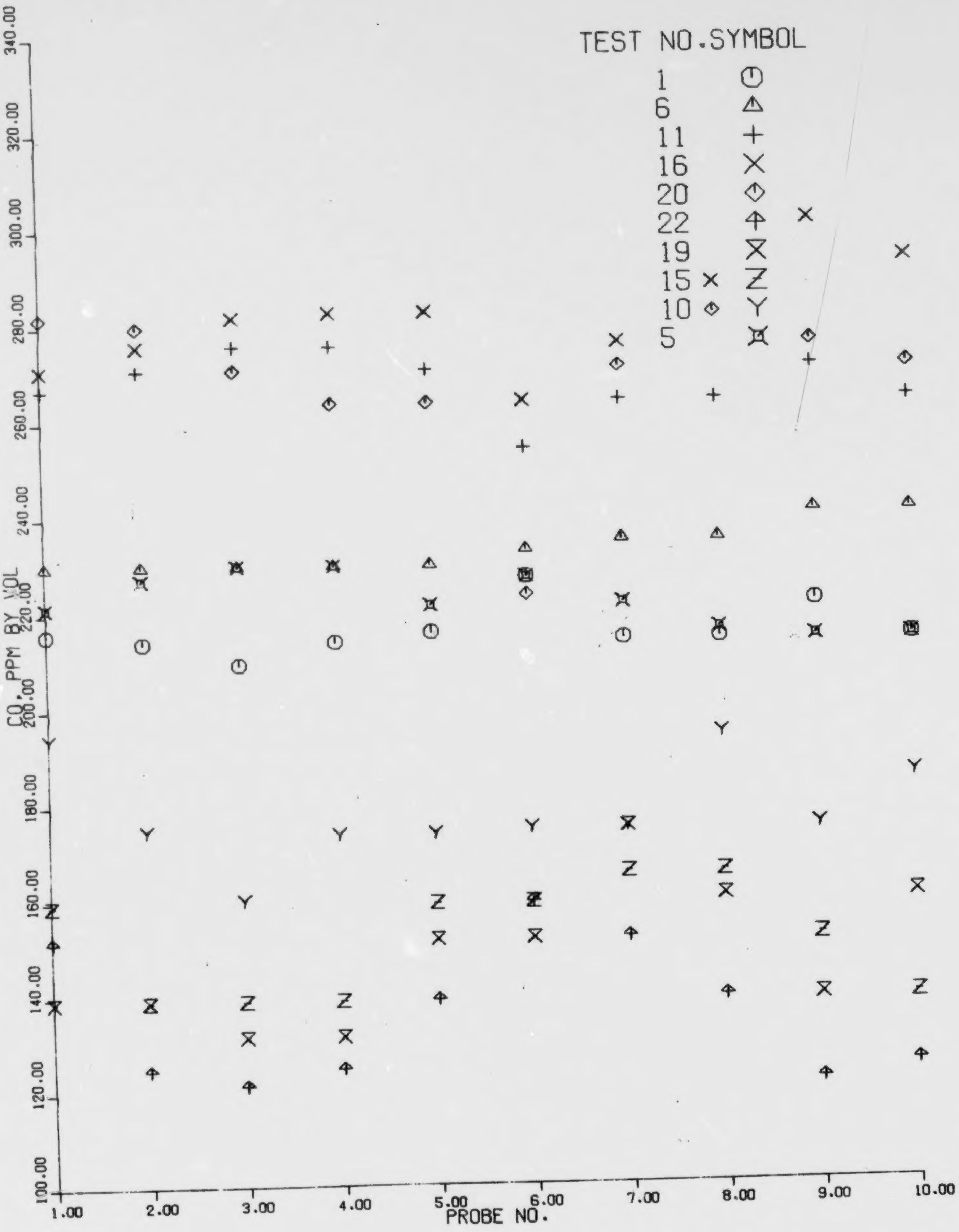

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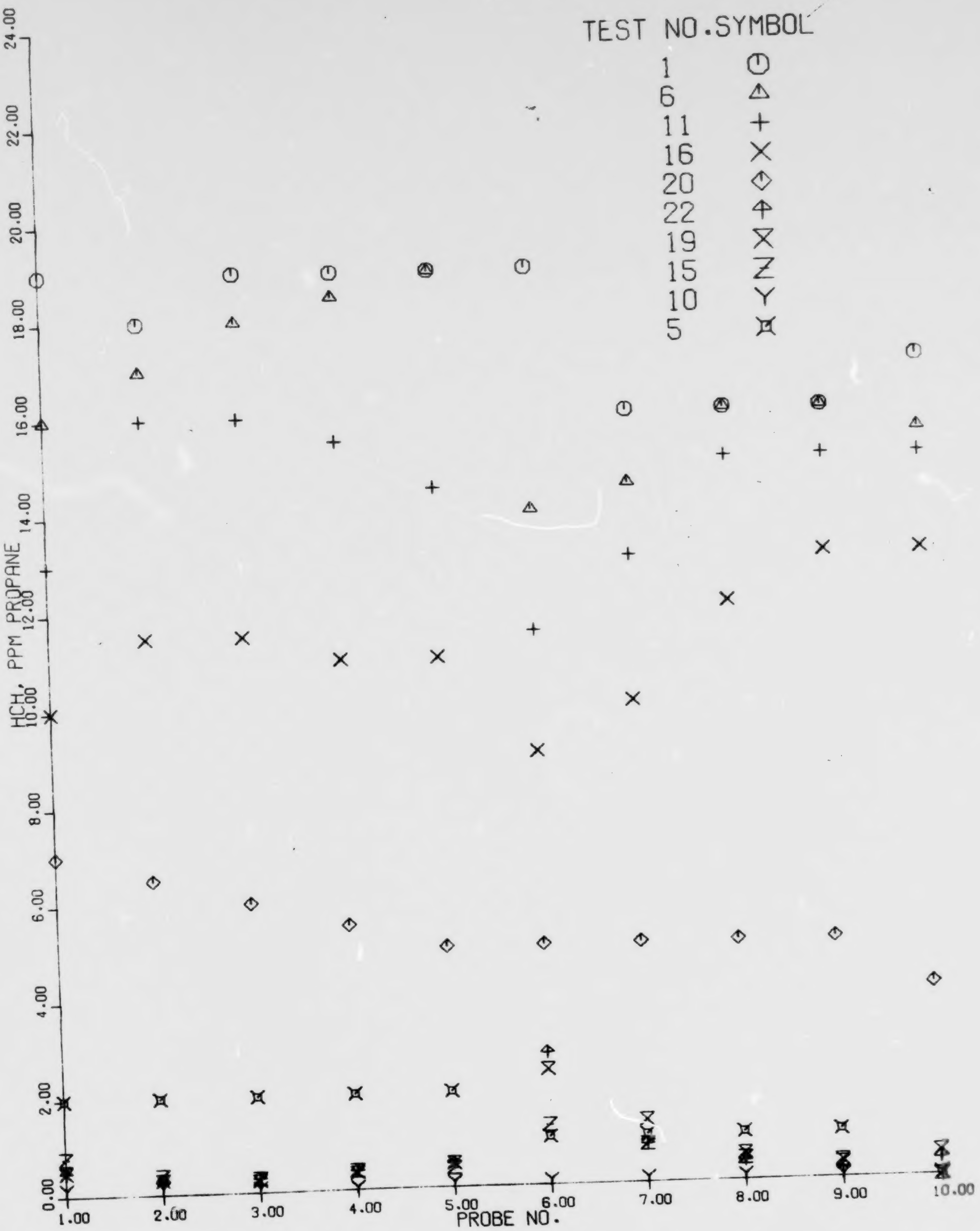

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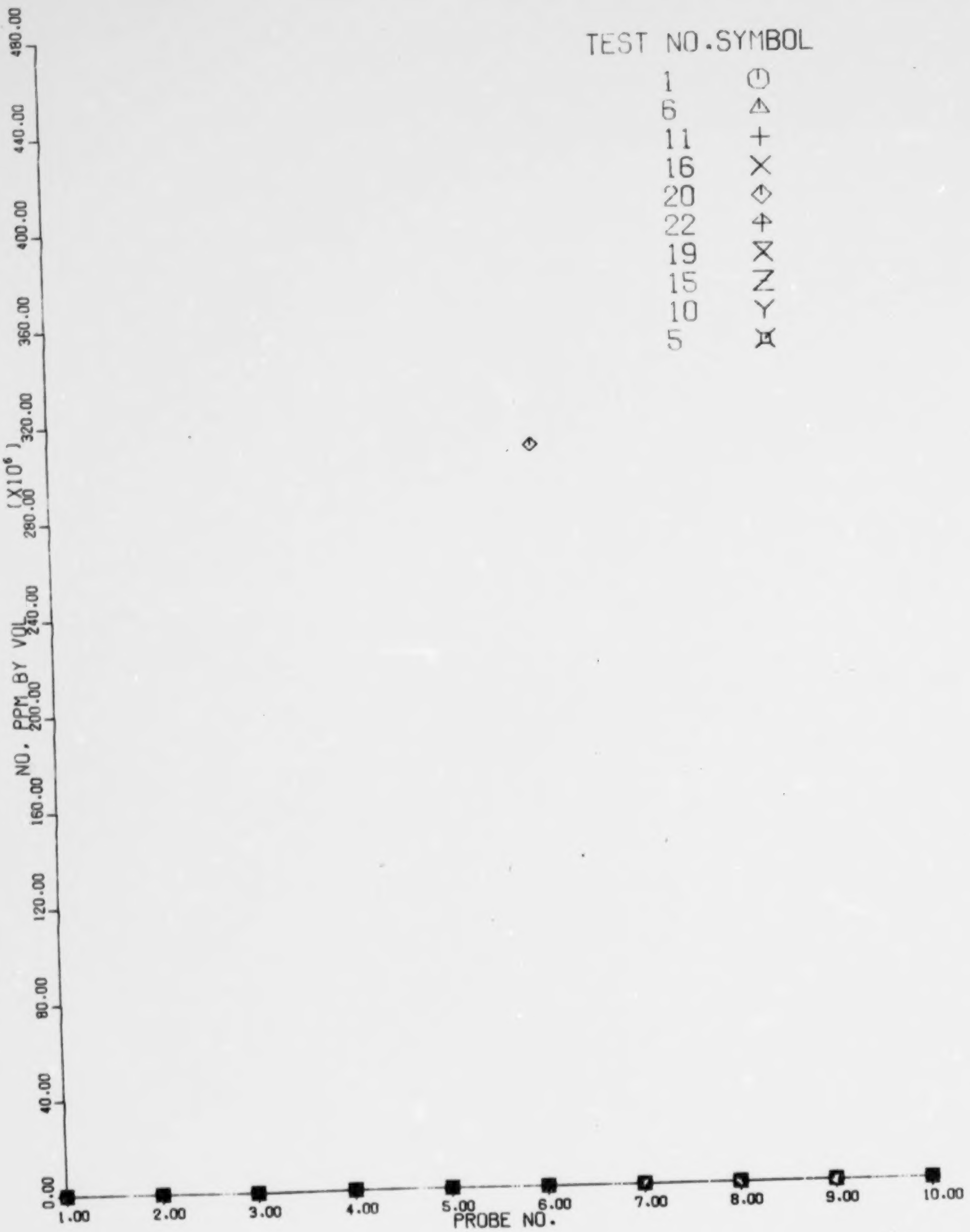

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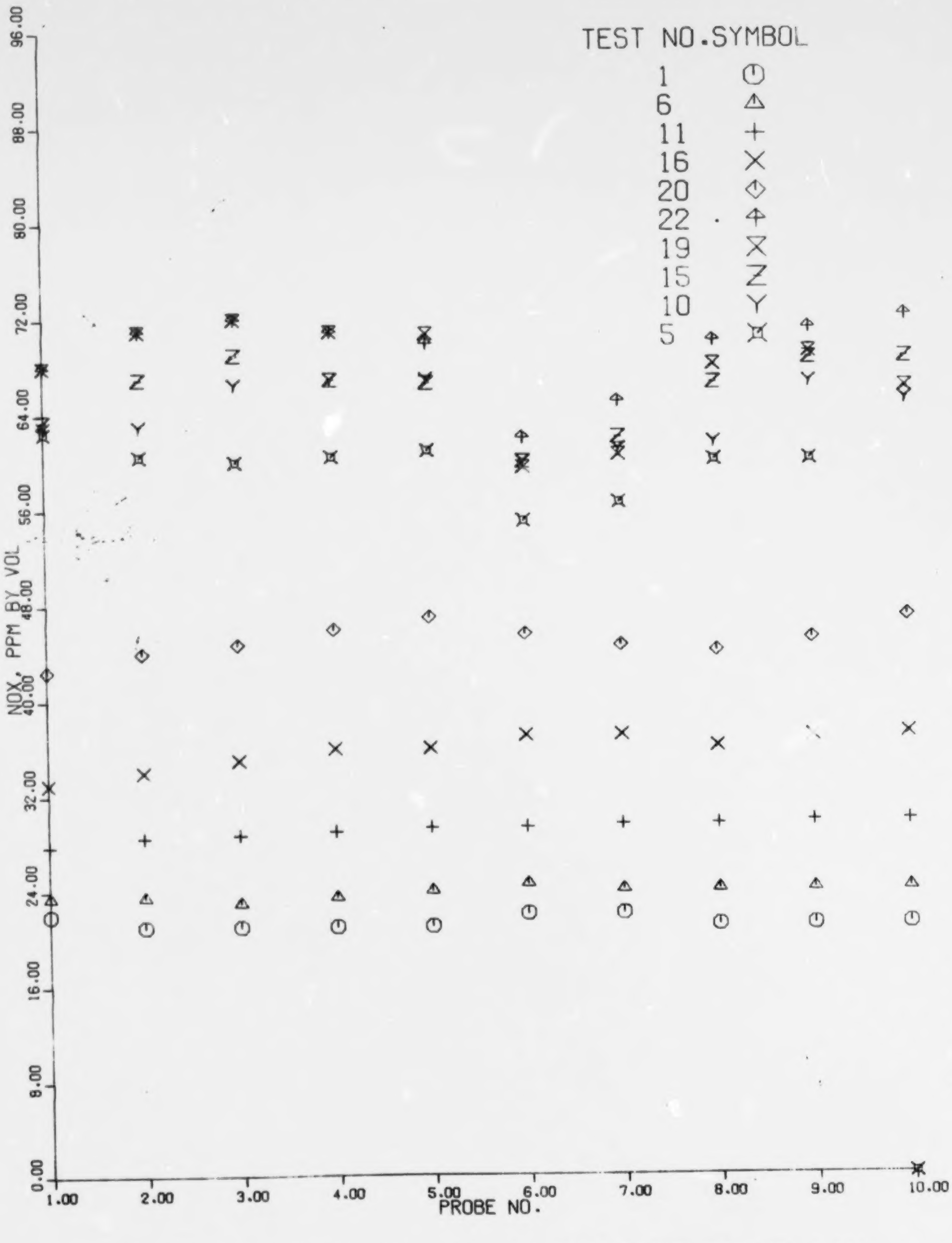

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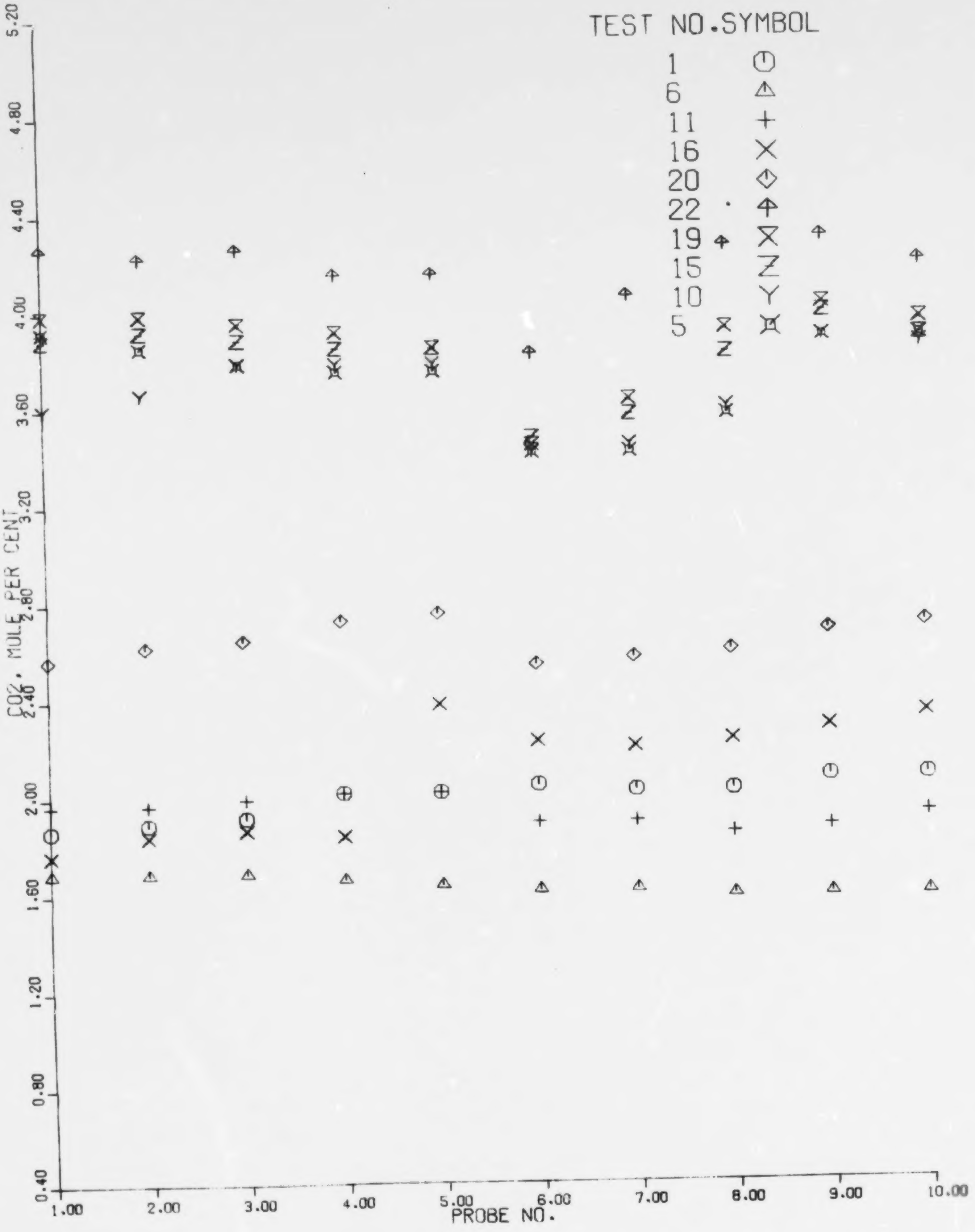

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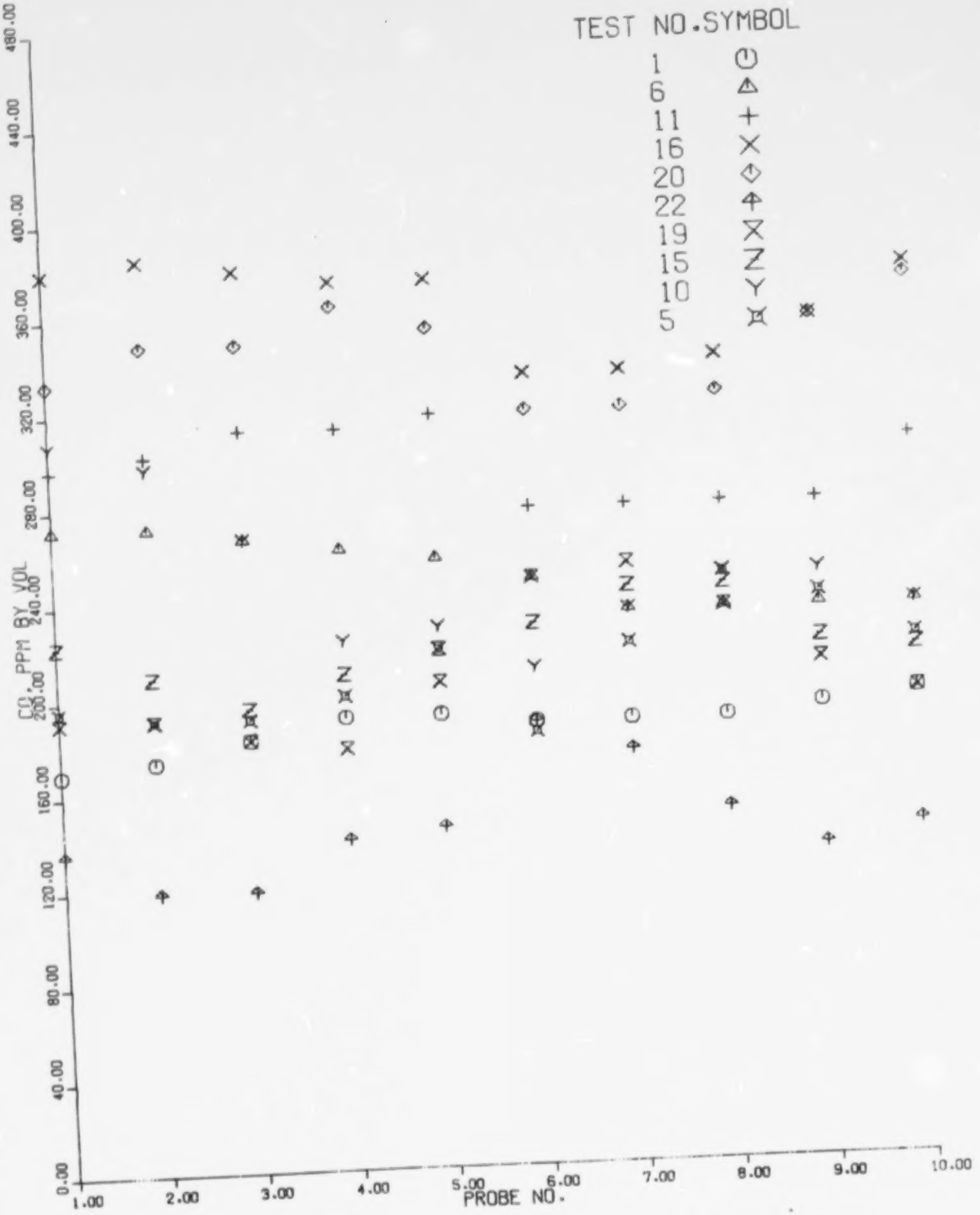

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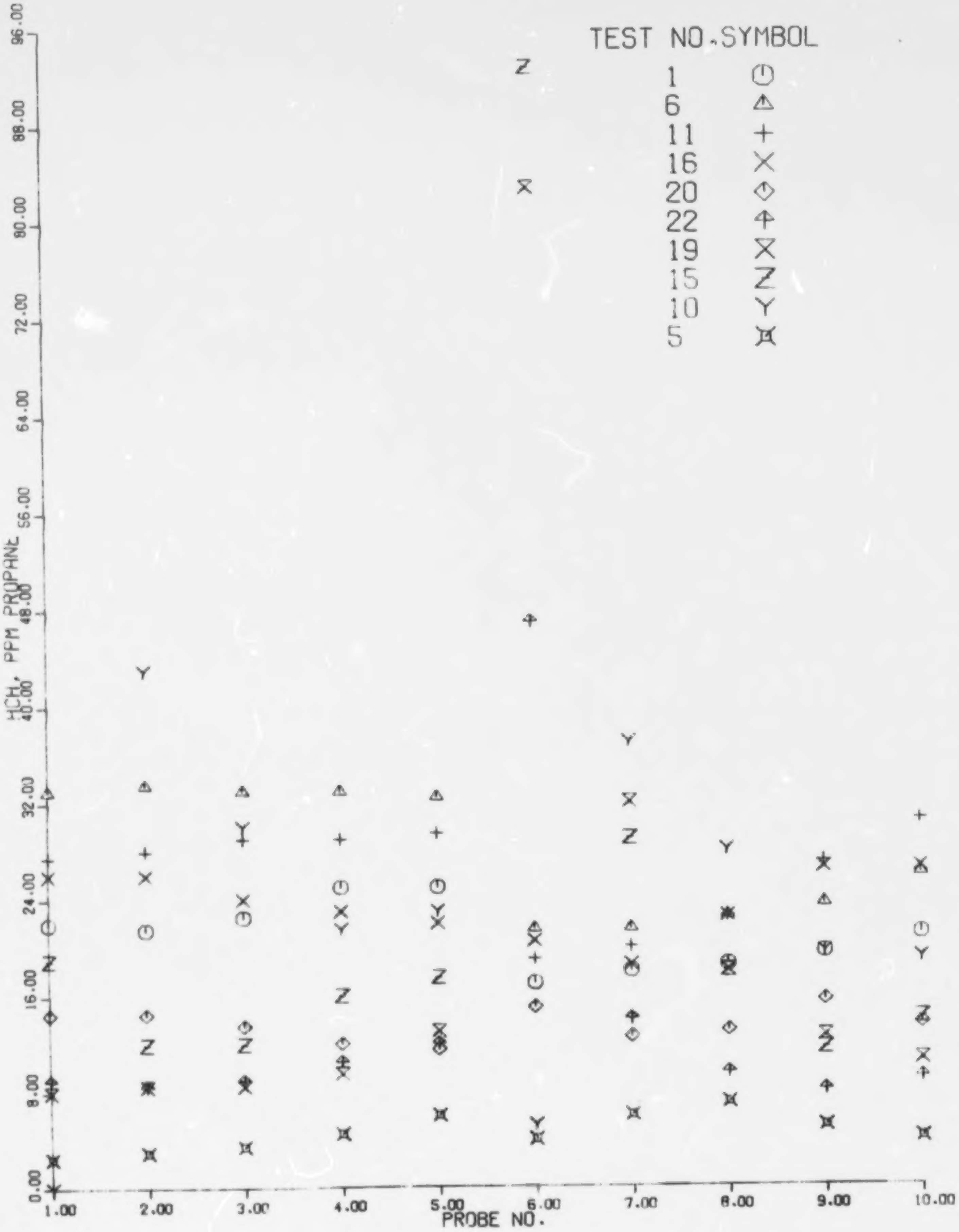

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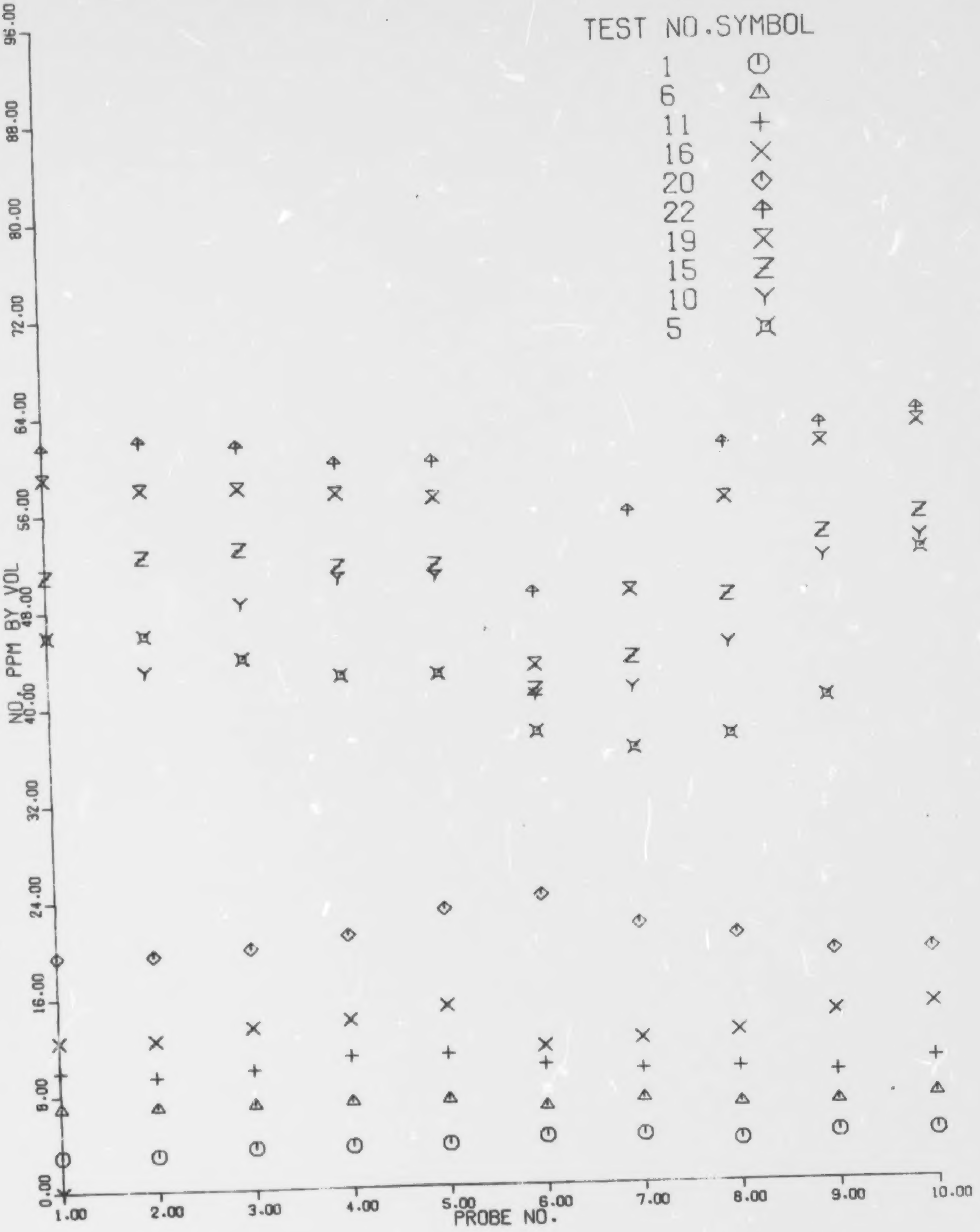

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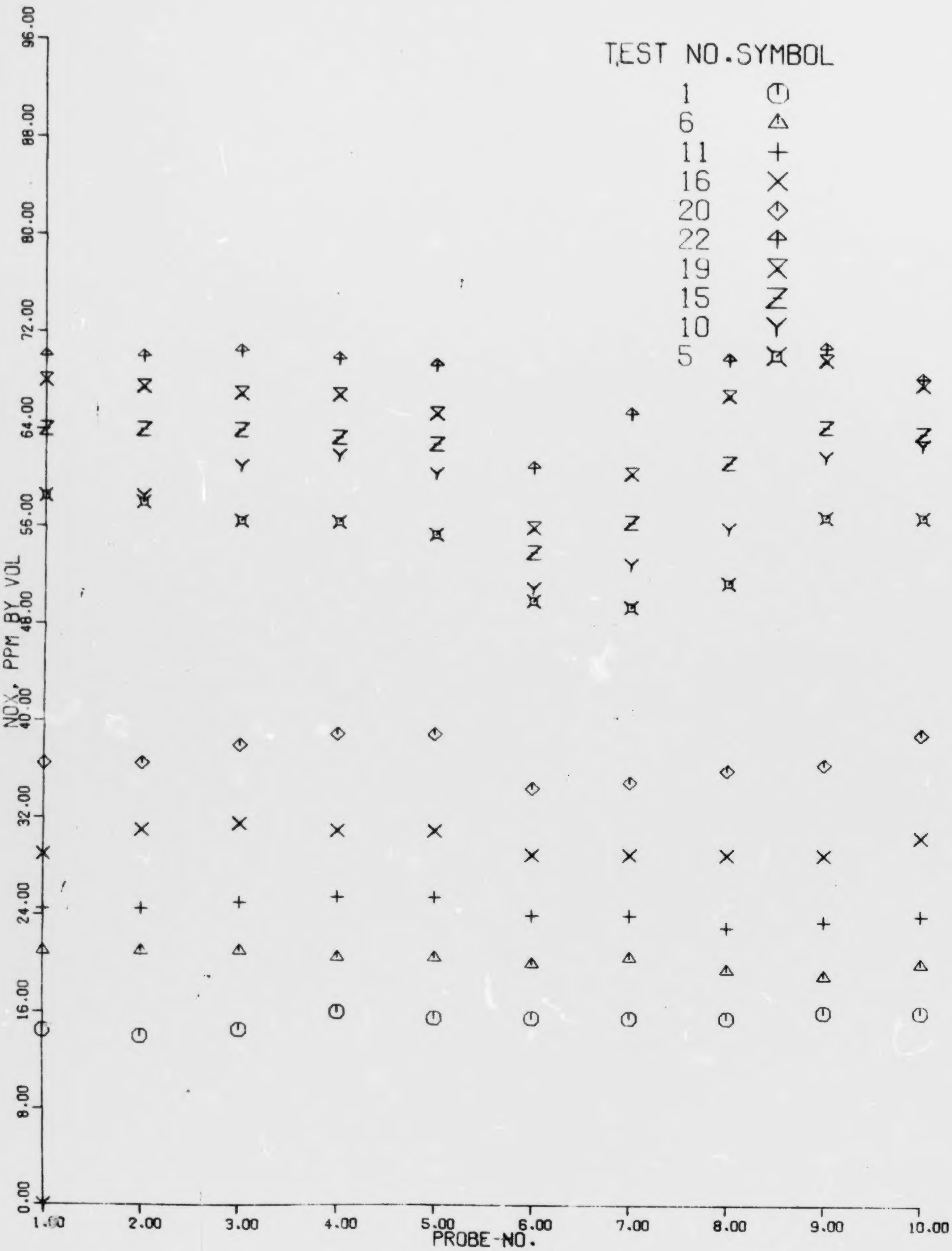

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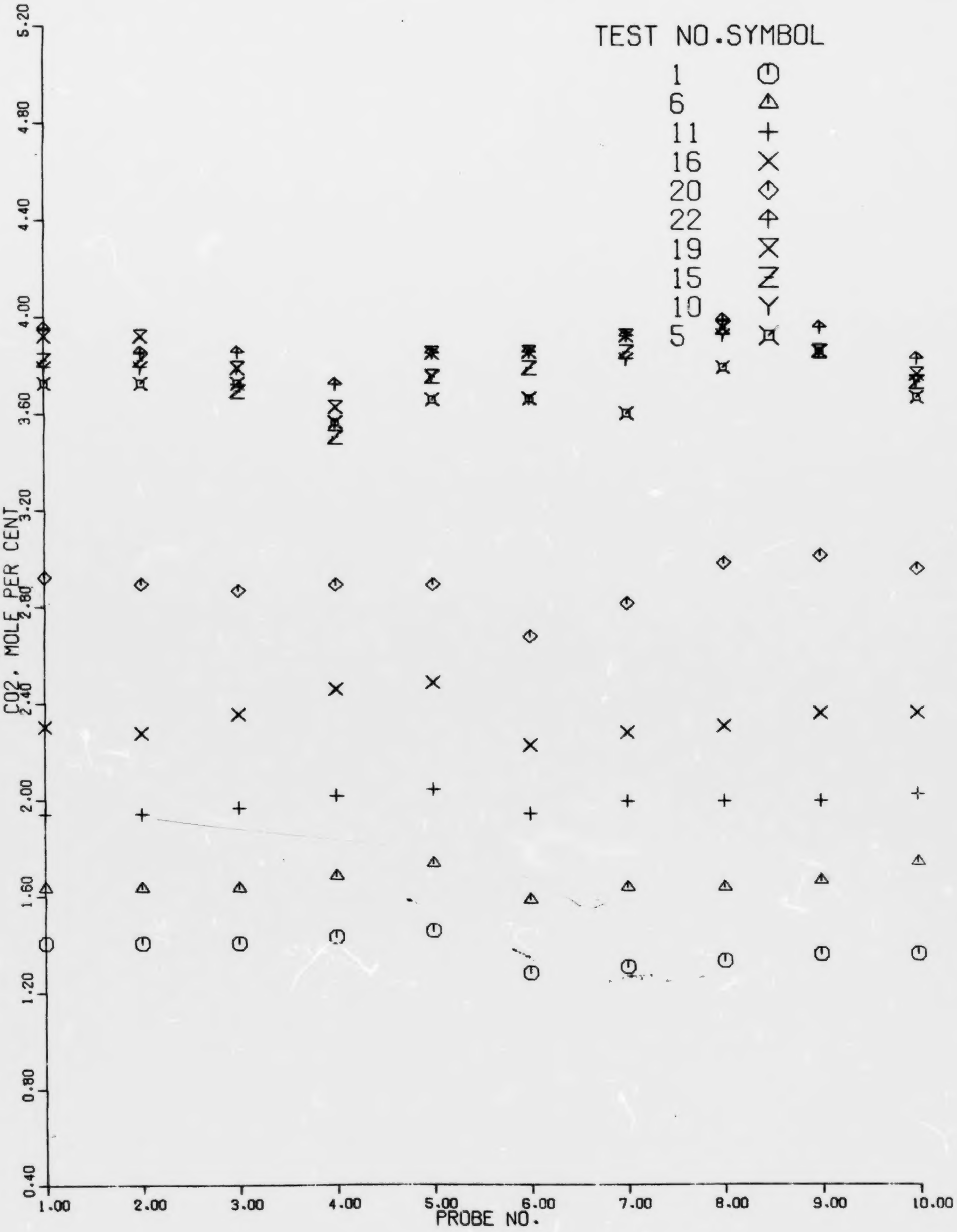

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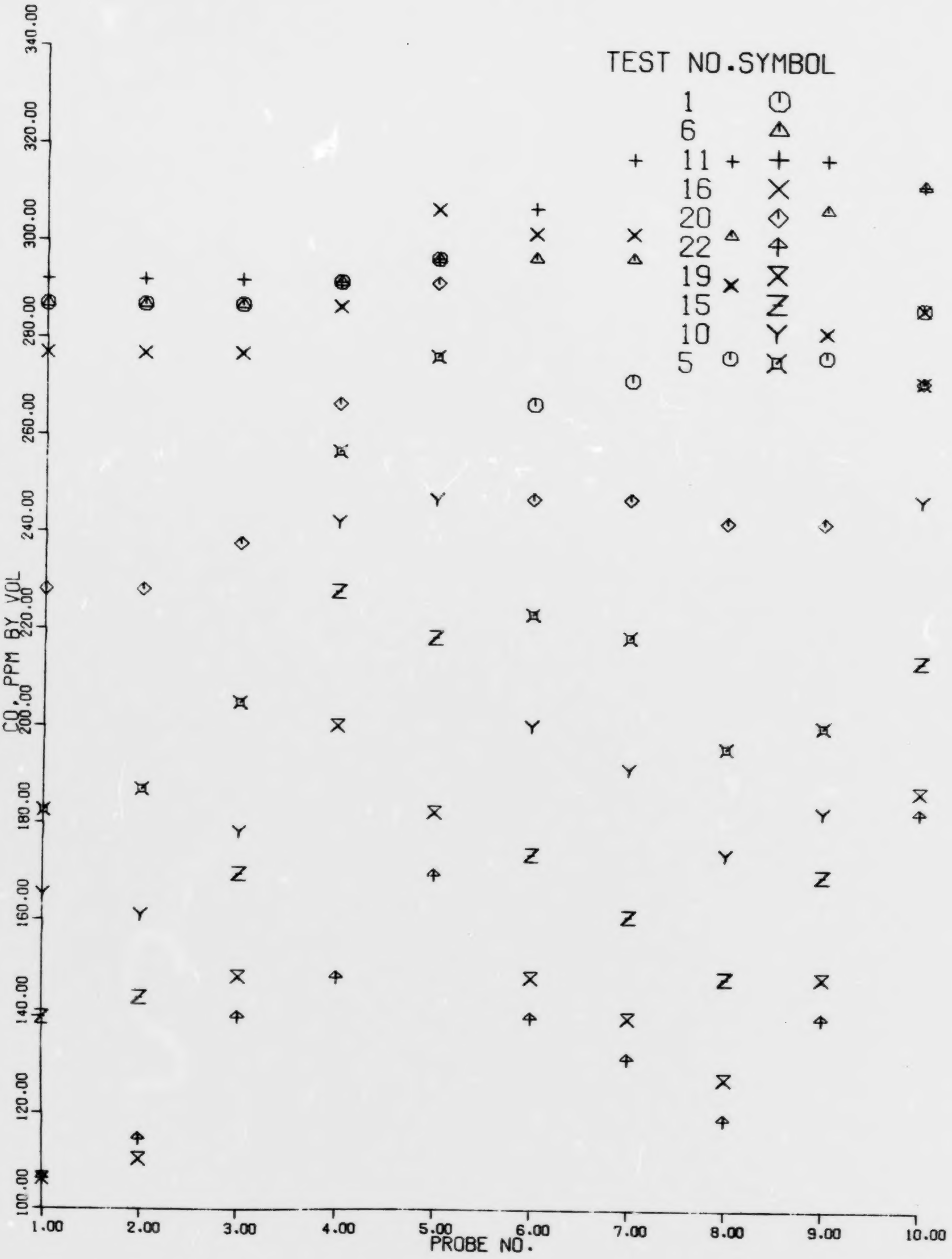

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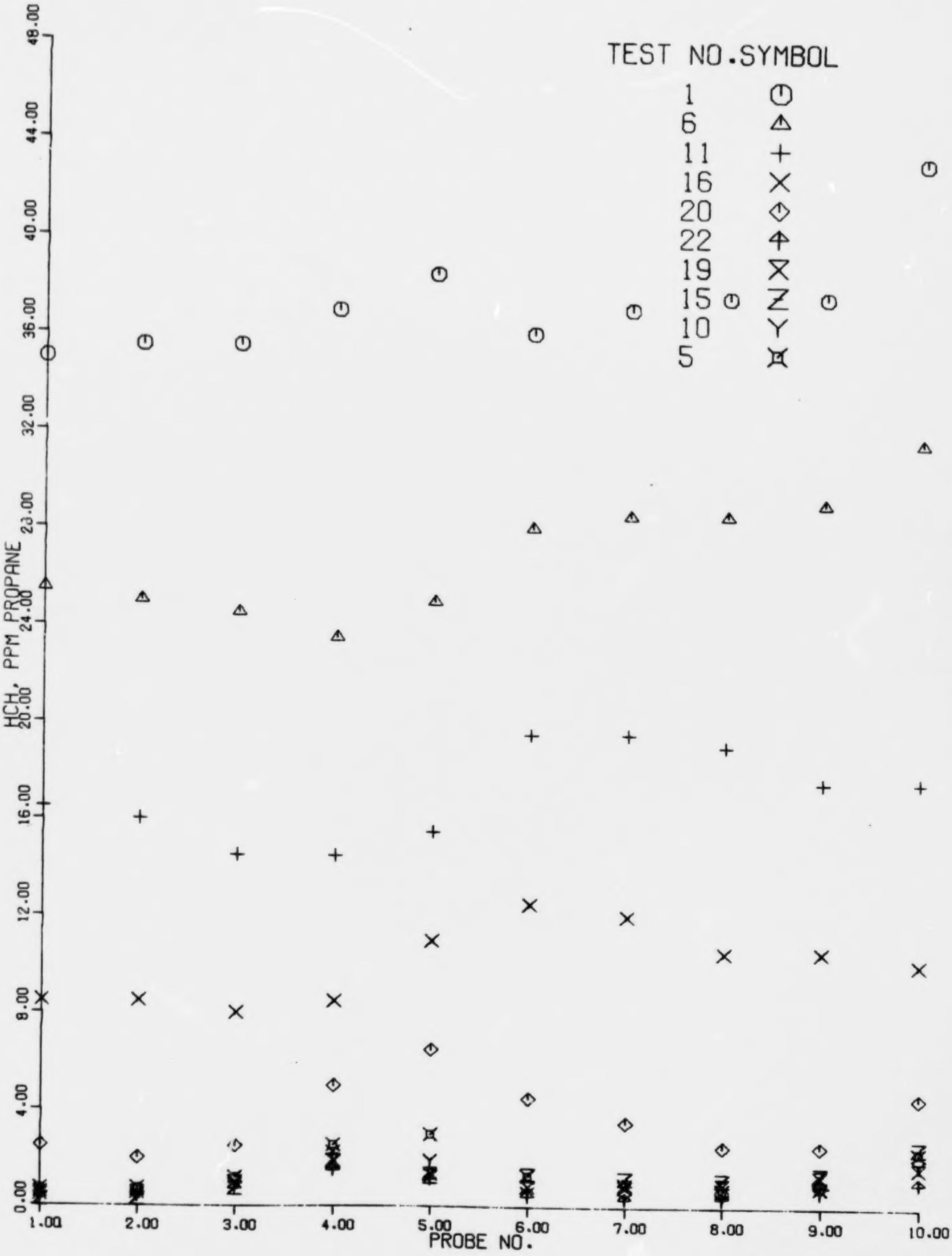

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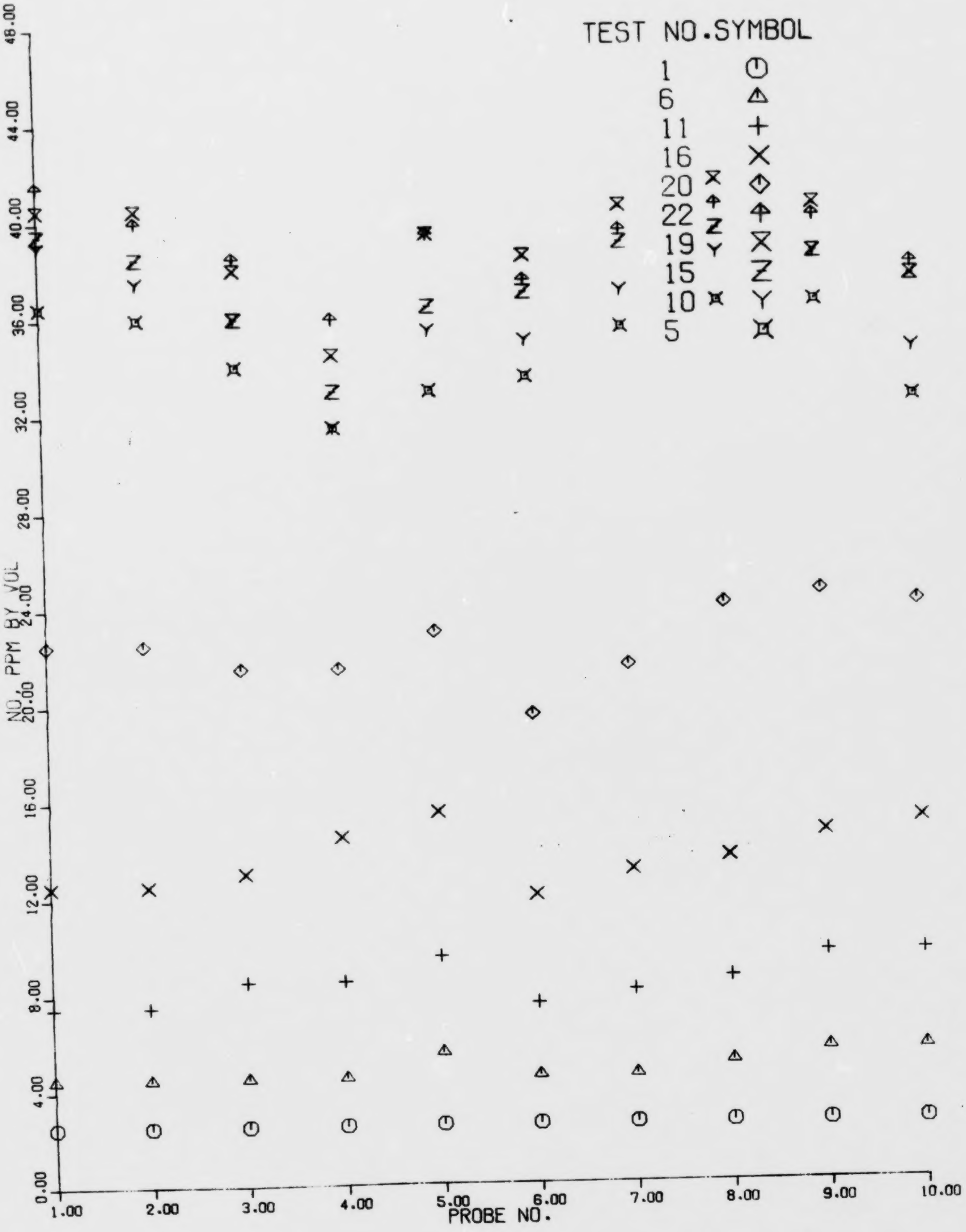

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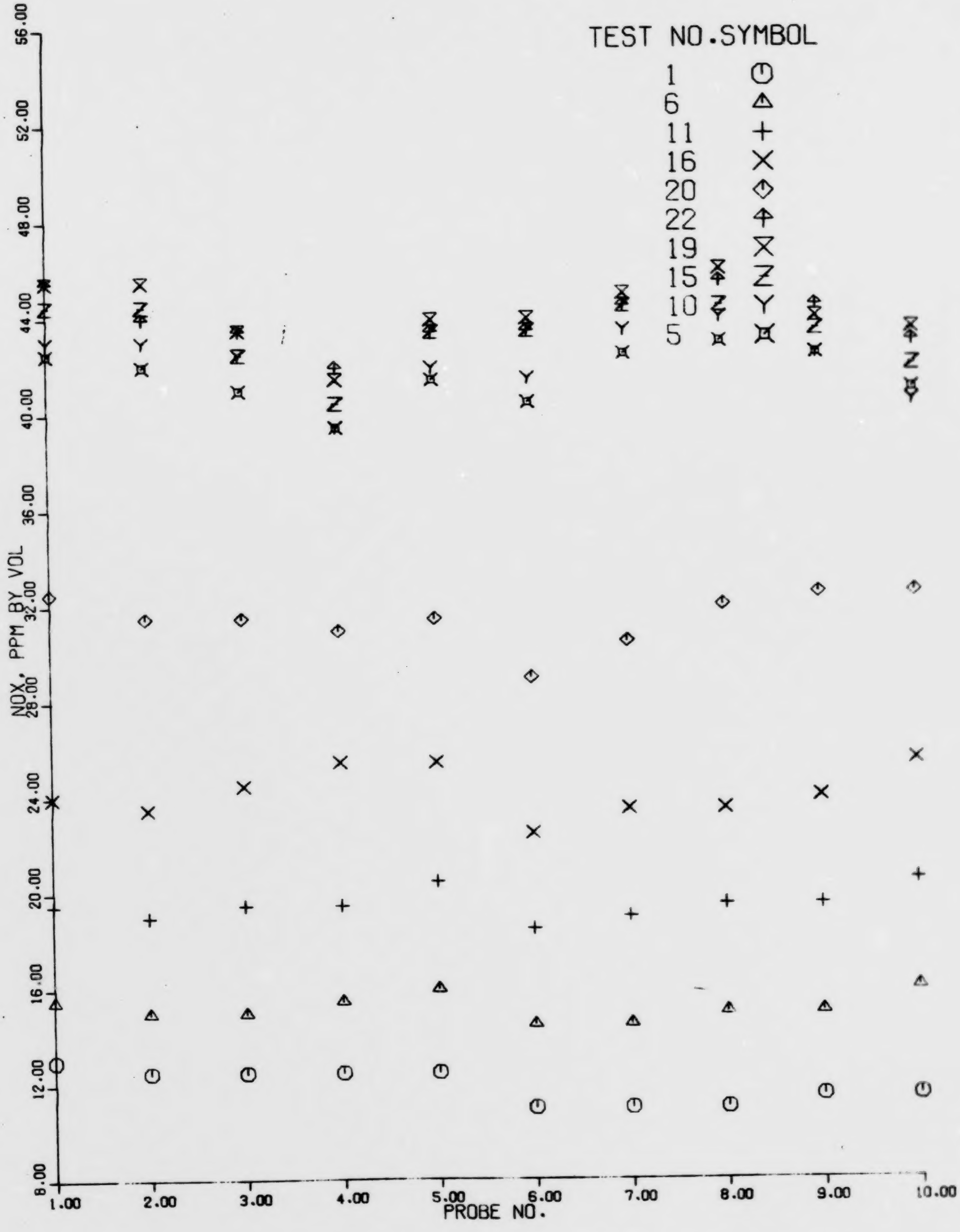

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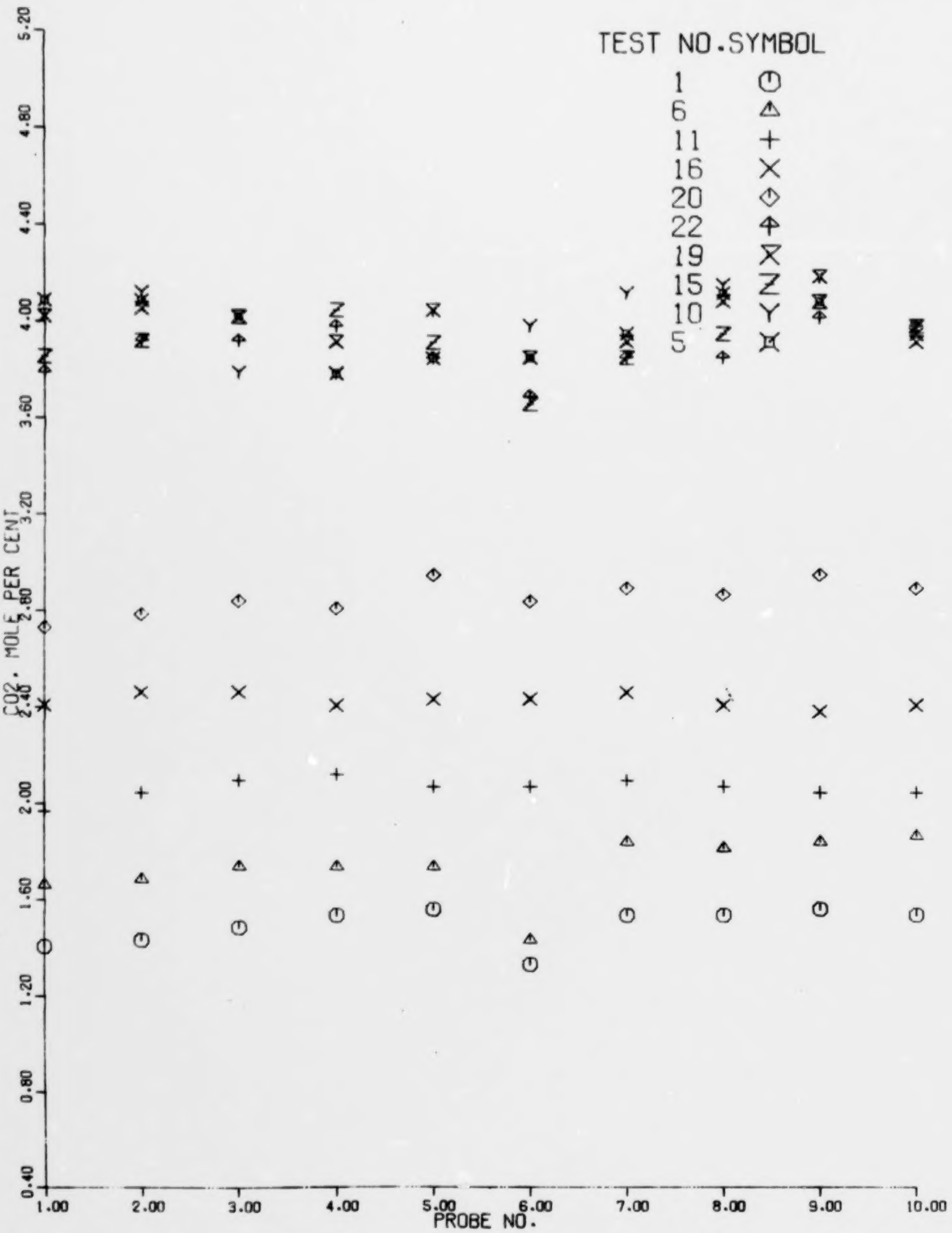

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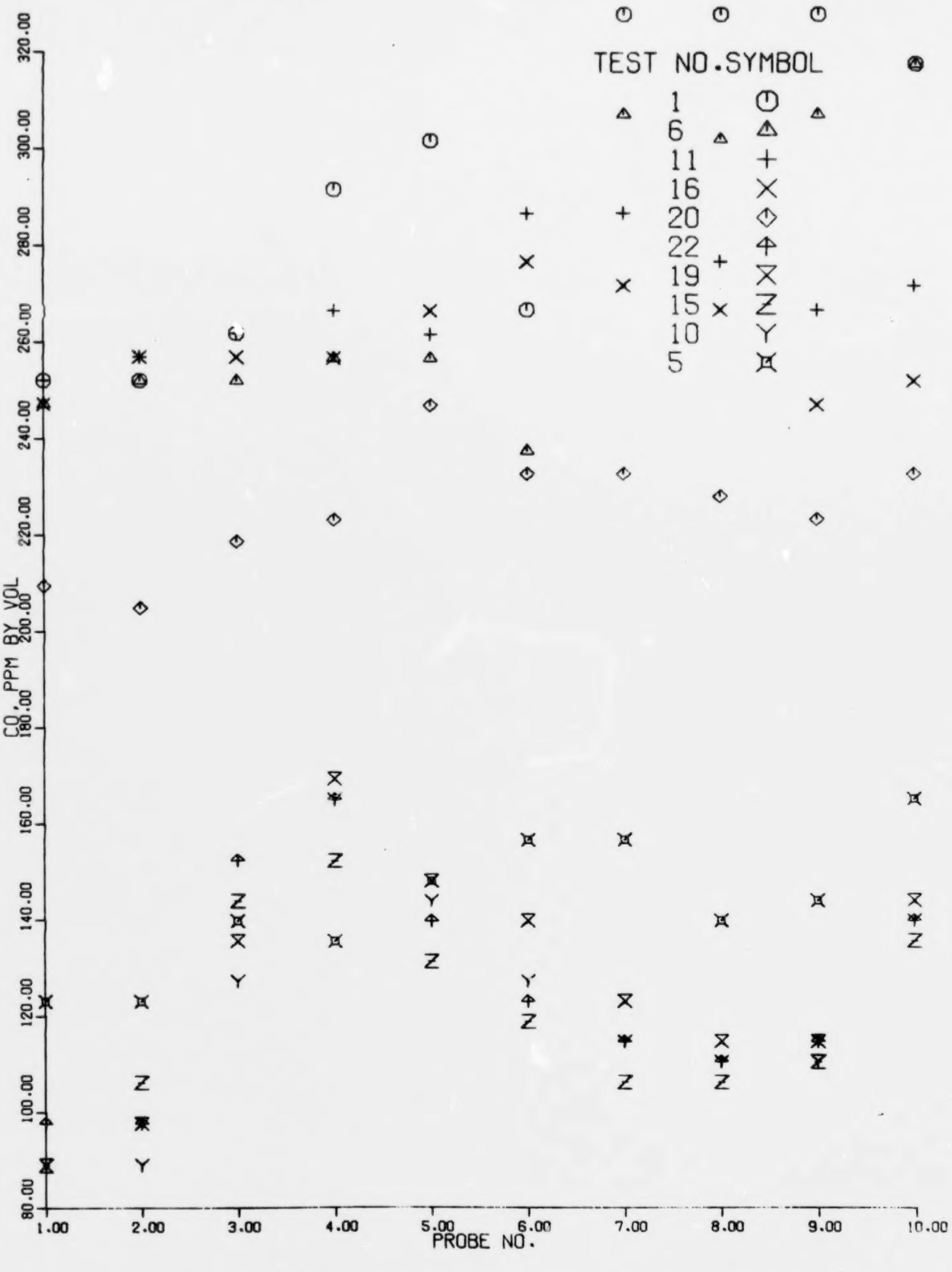

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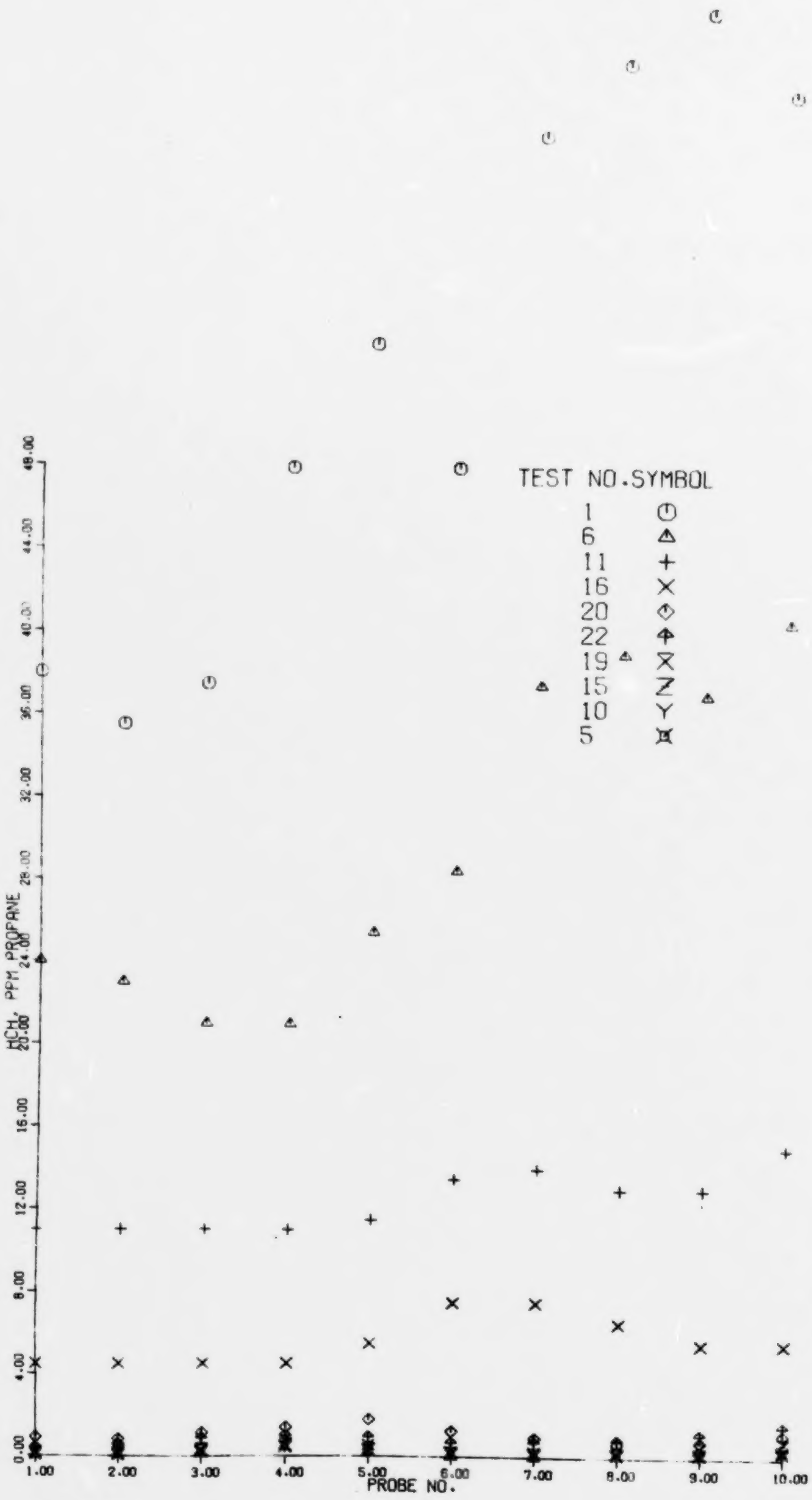

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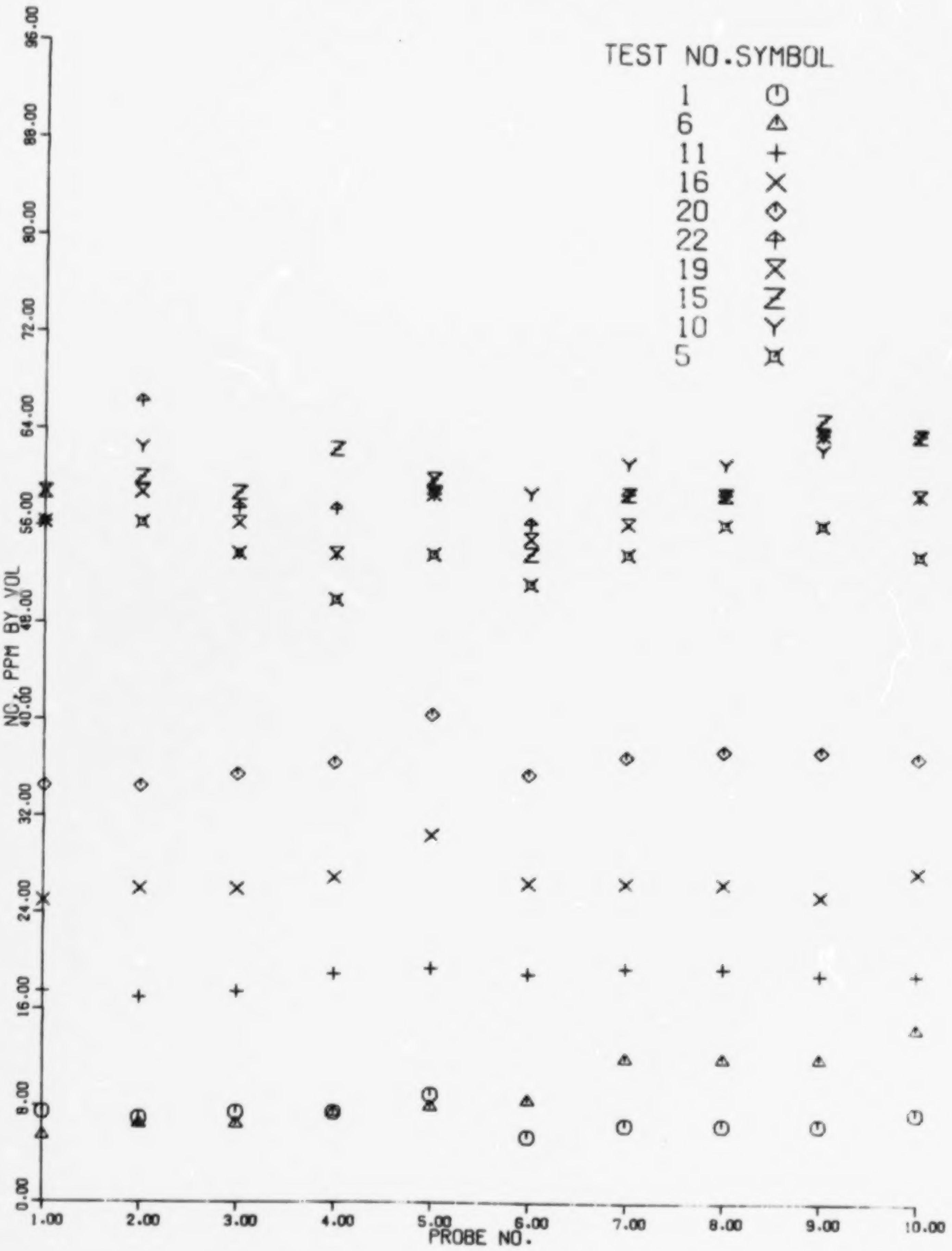

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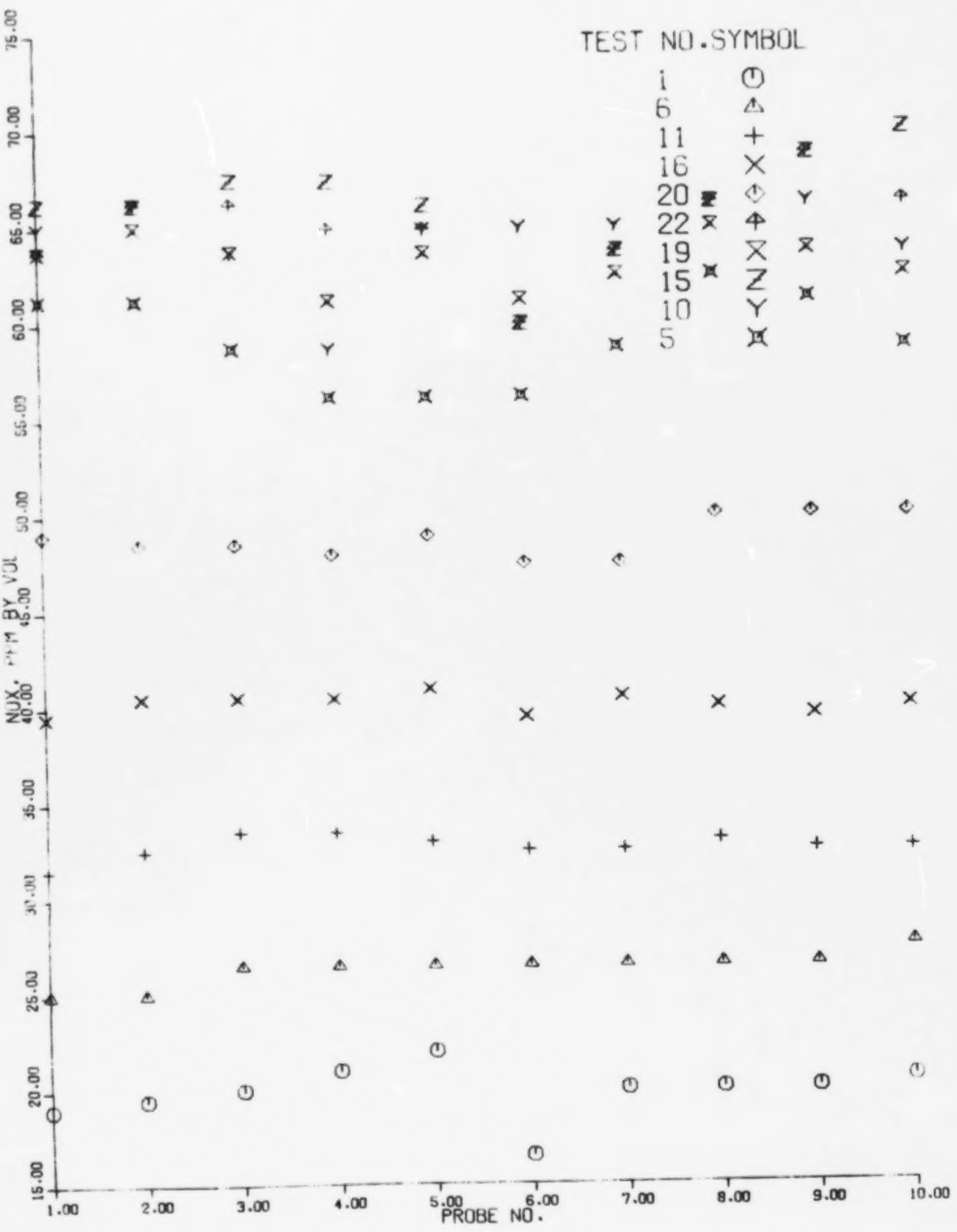

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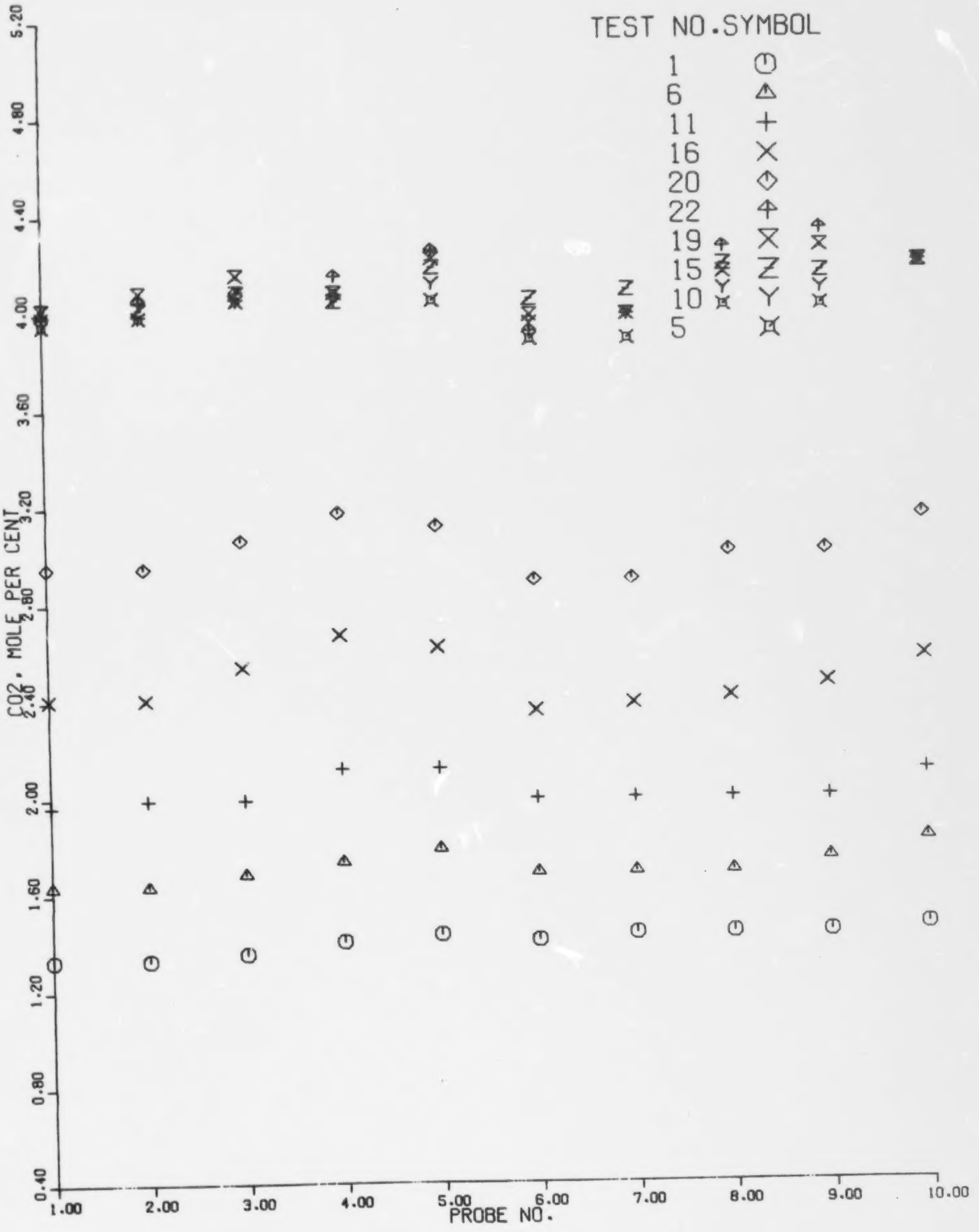

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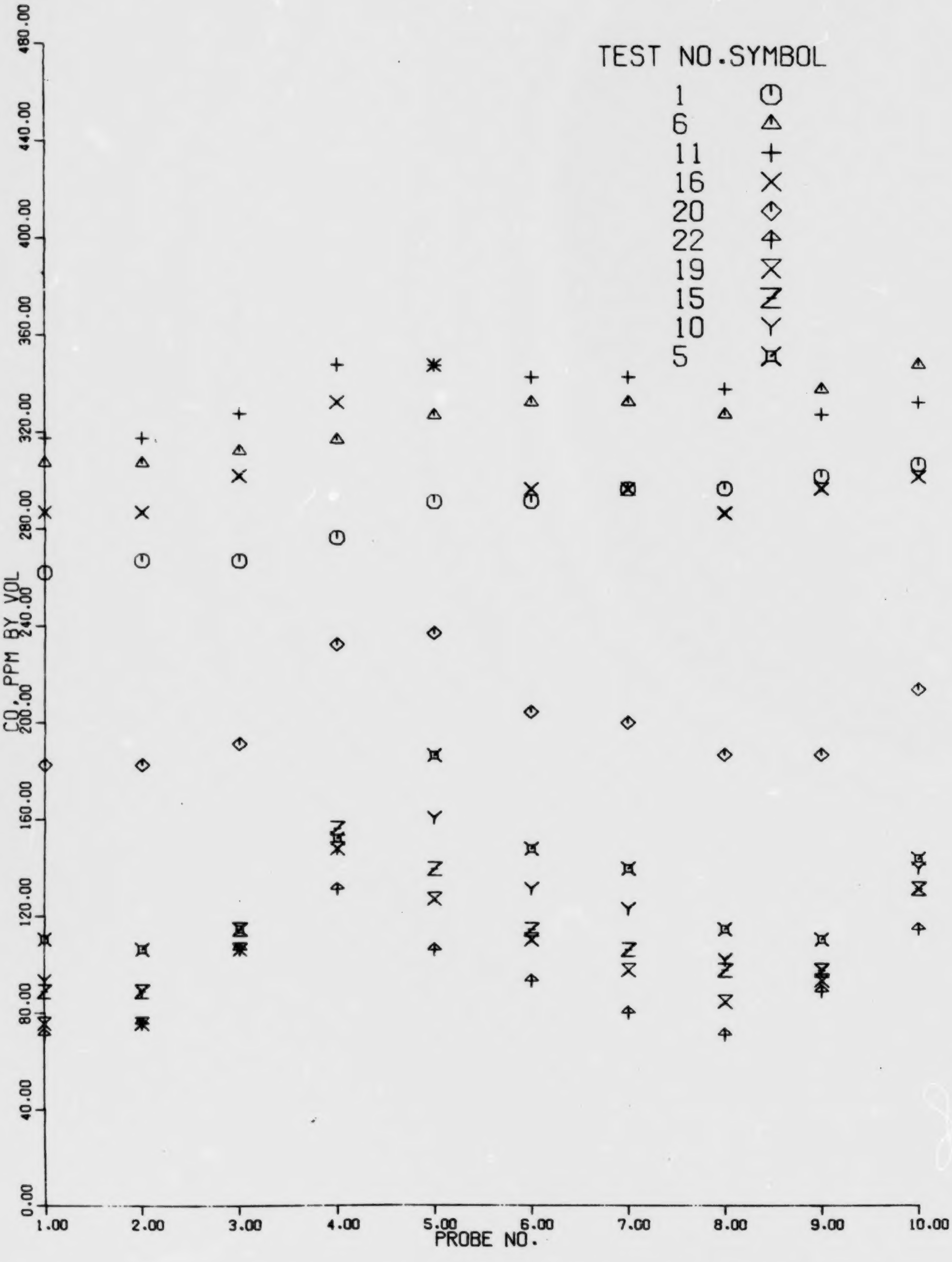

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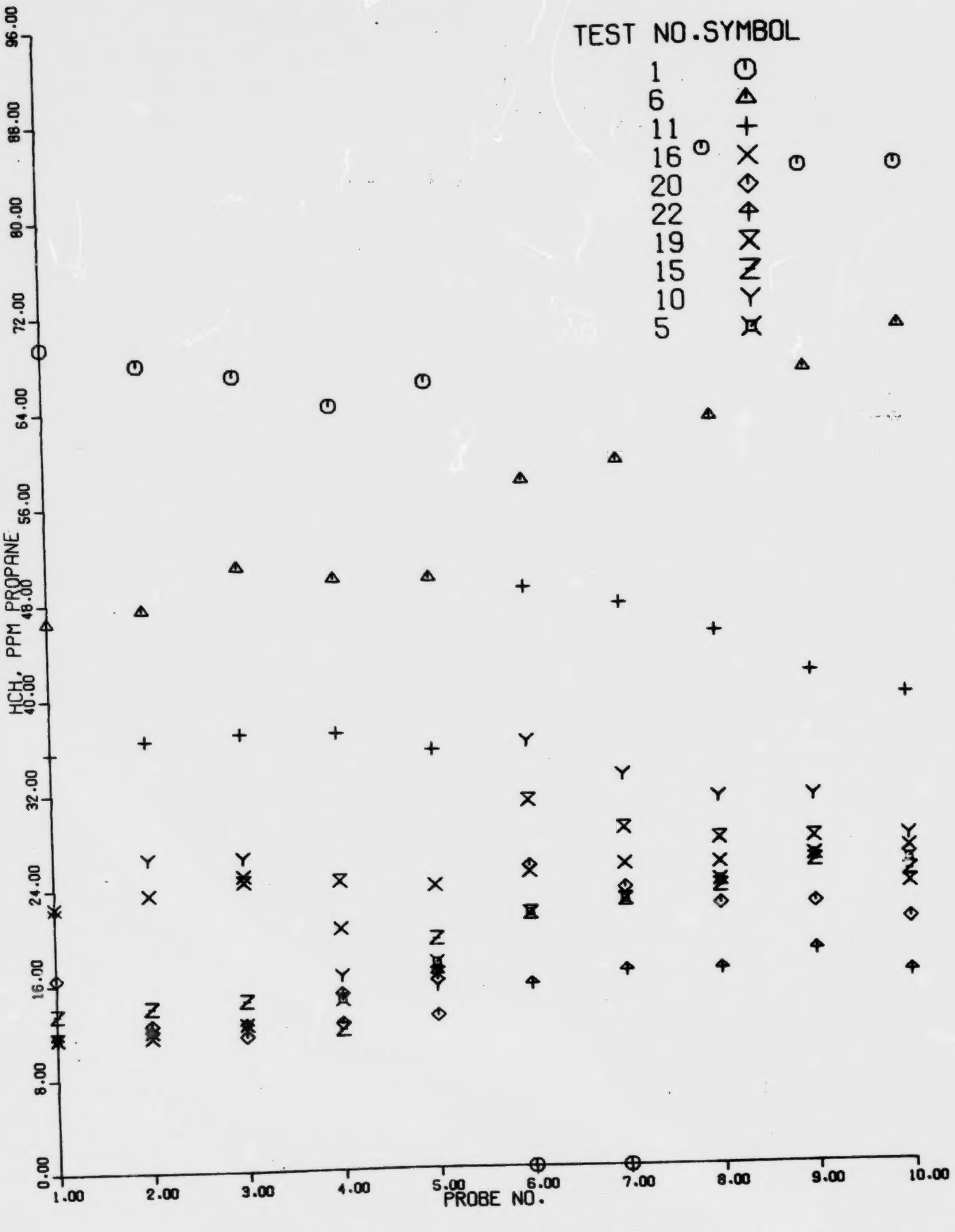

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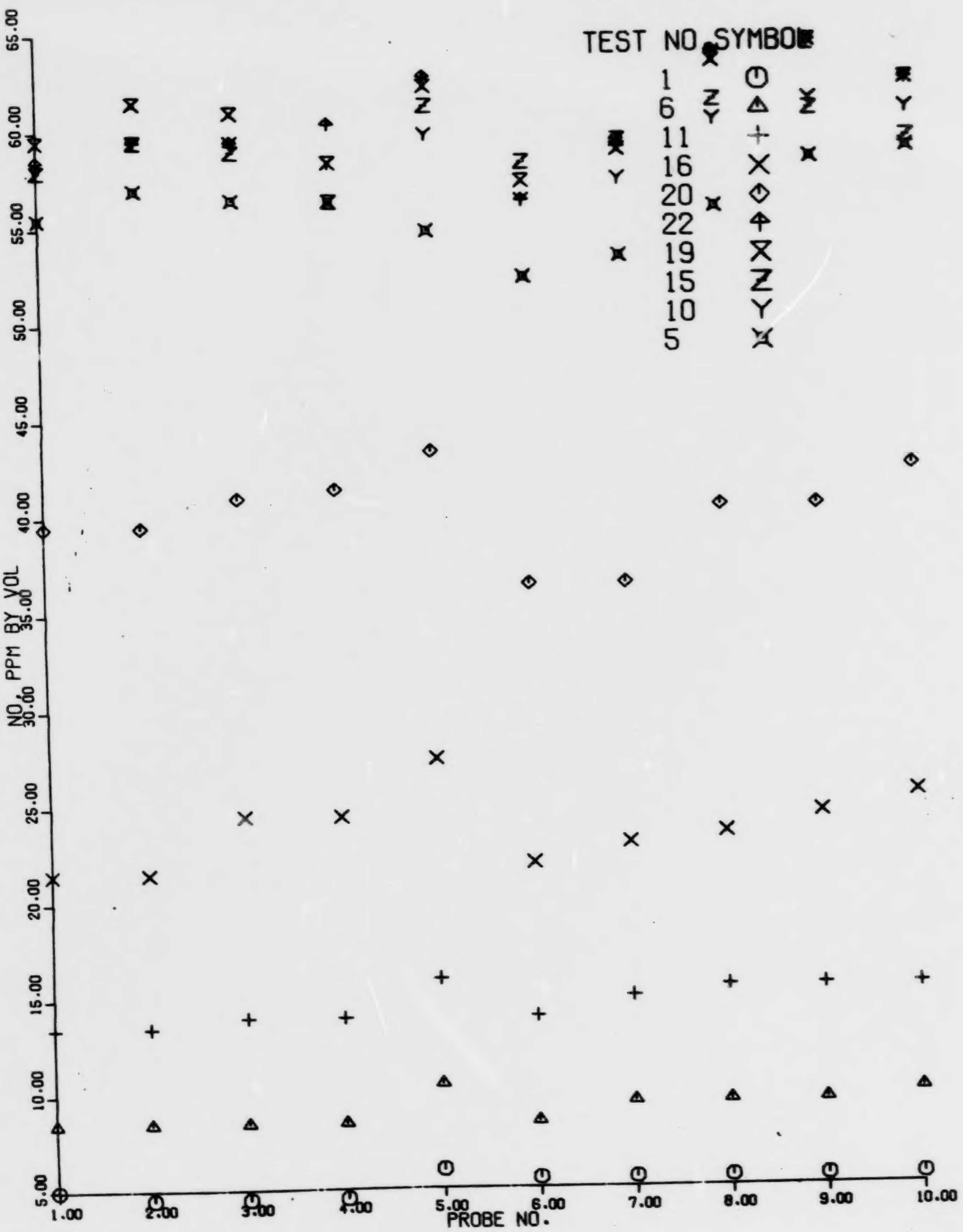

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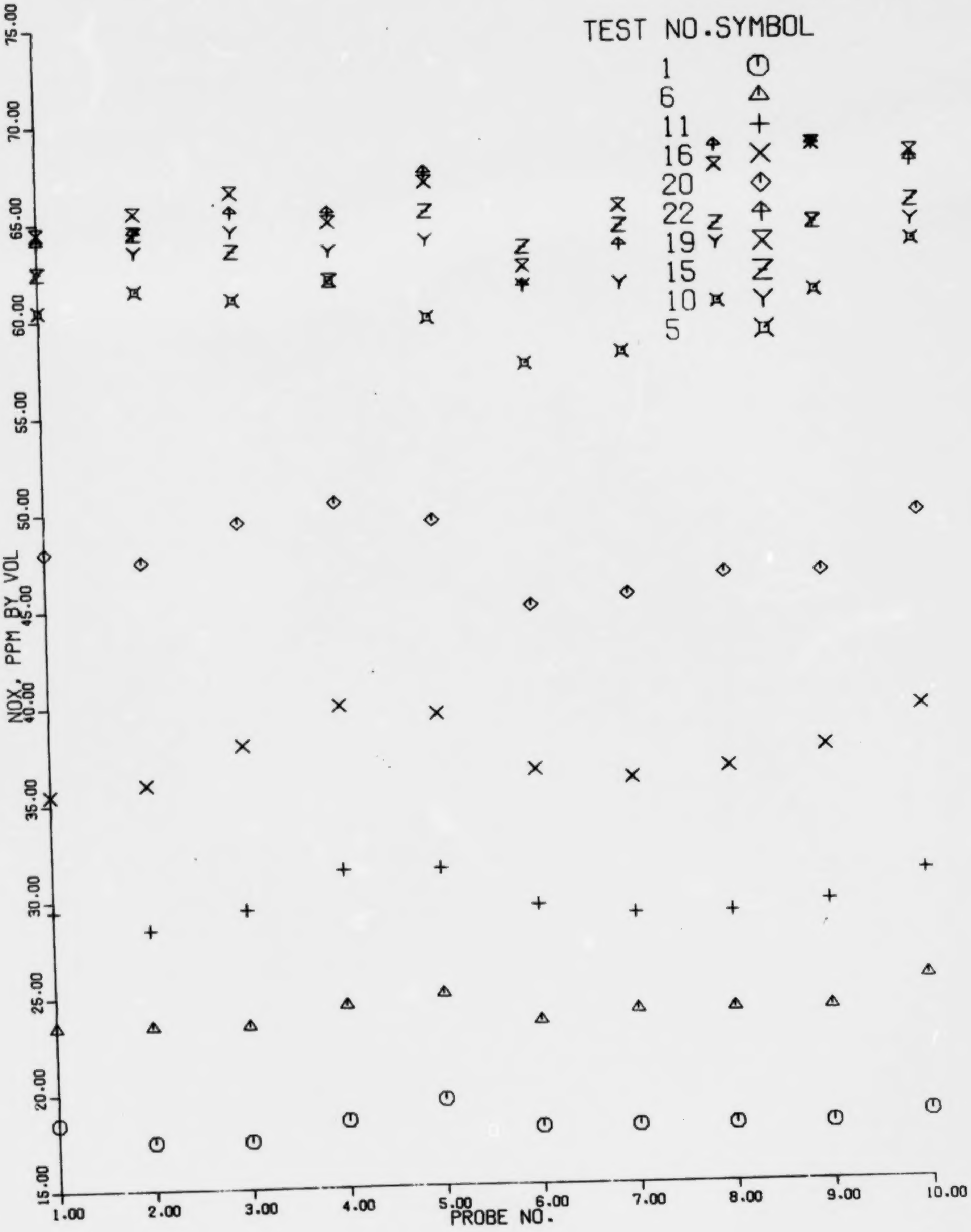

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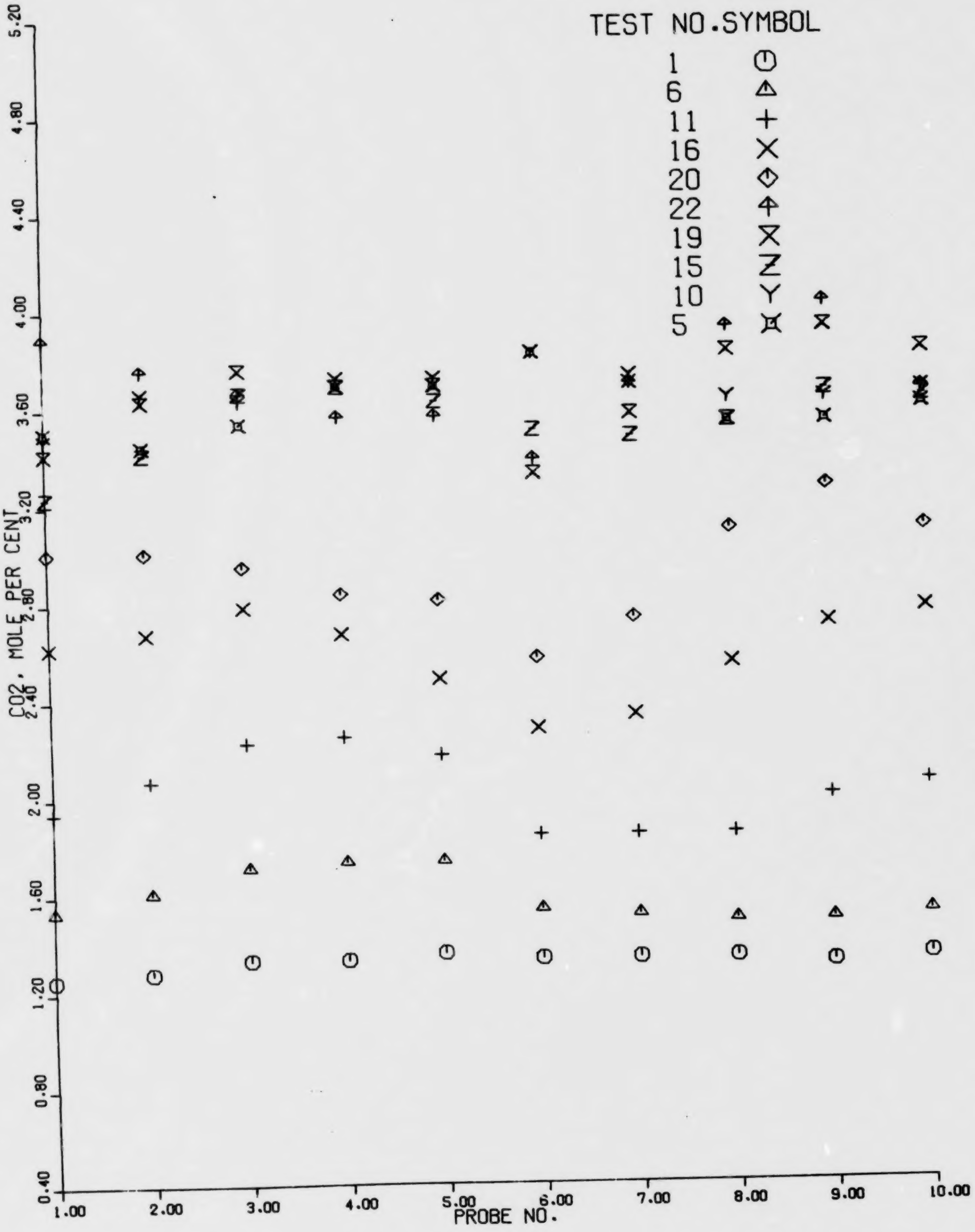
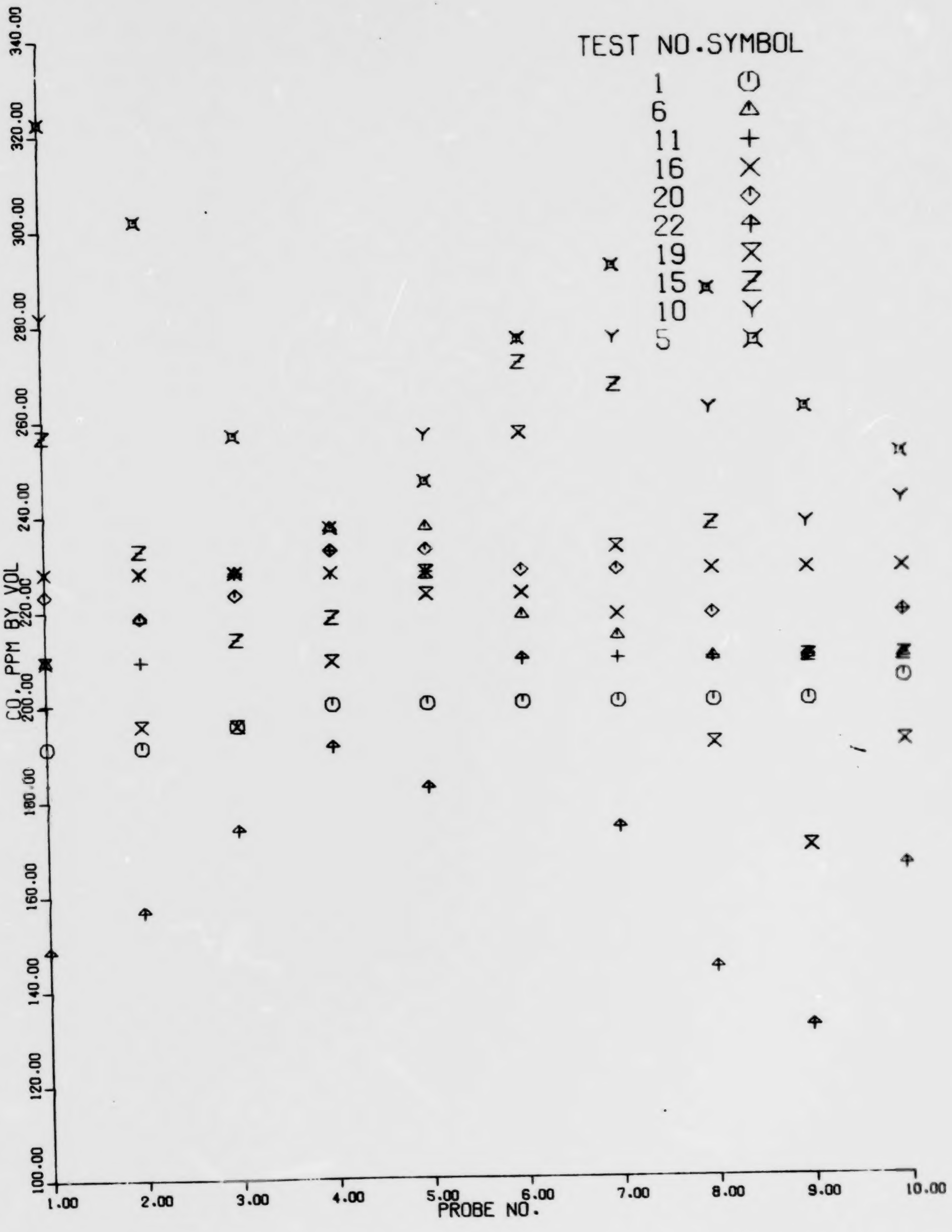


GTCP85-115 S/N P-18725 ,O/H, FUEL JP5 DATE 5/13/71 CELL D-115



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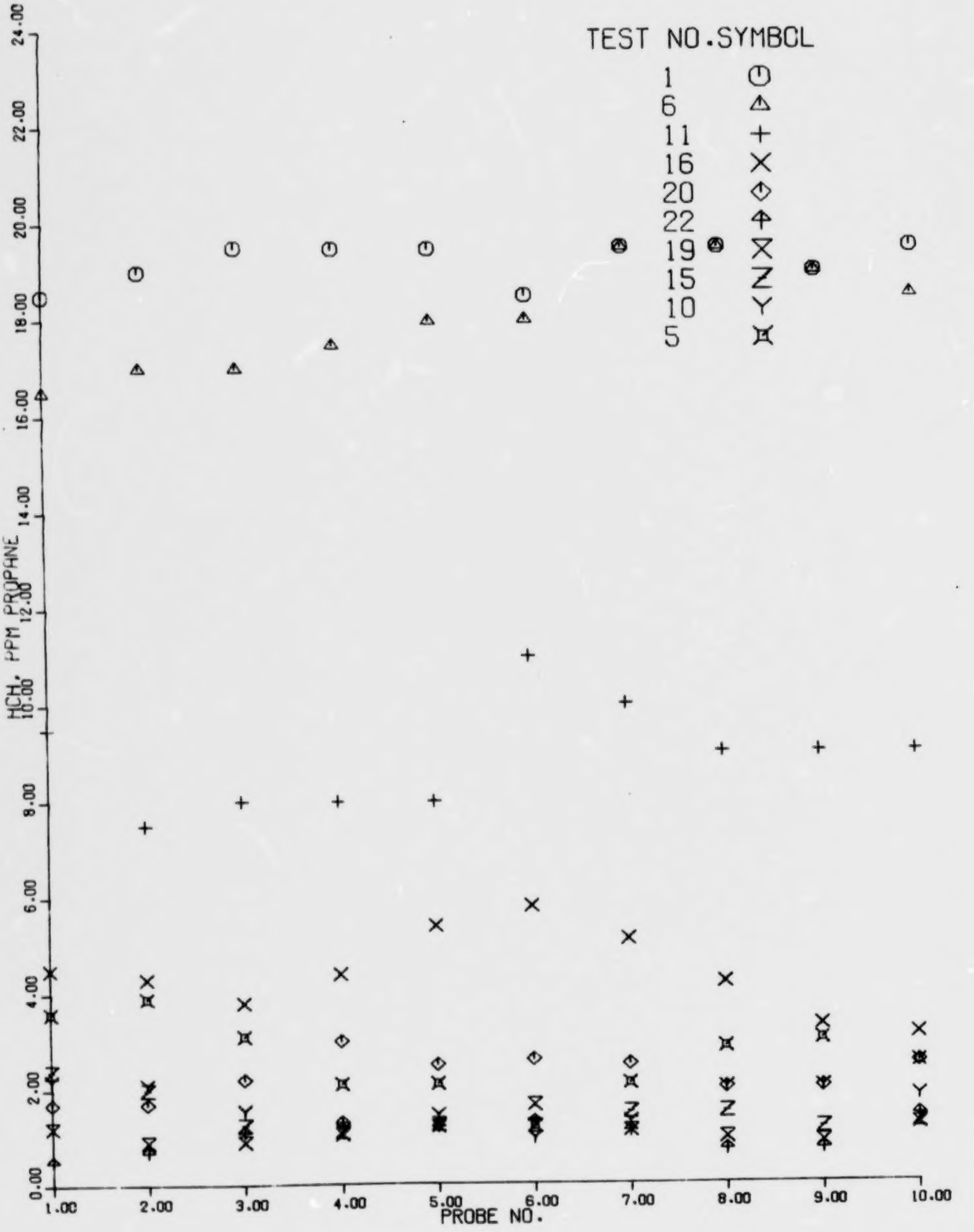

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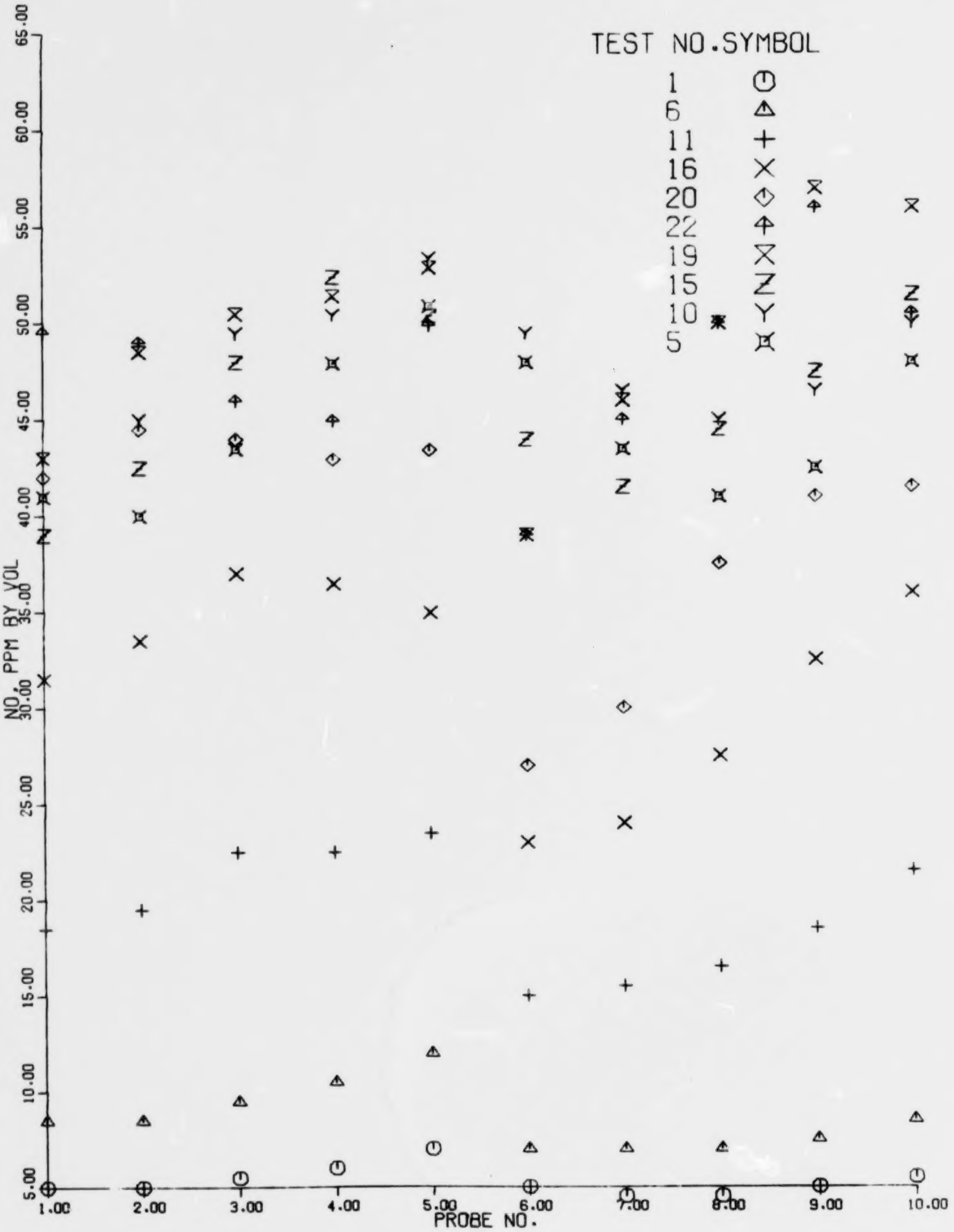

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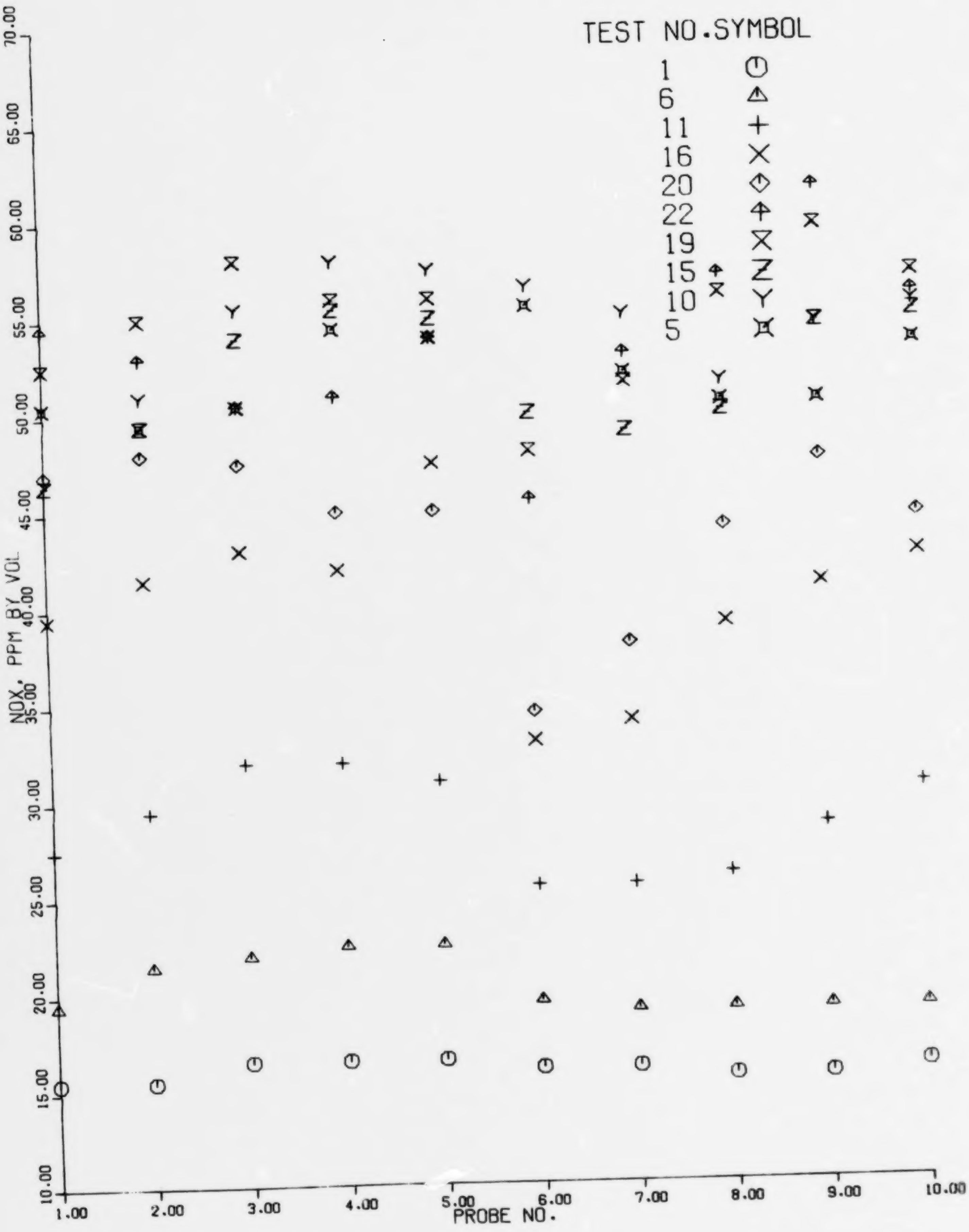

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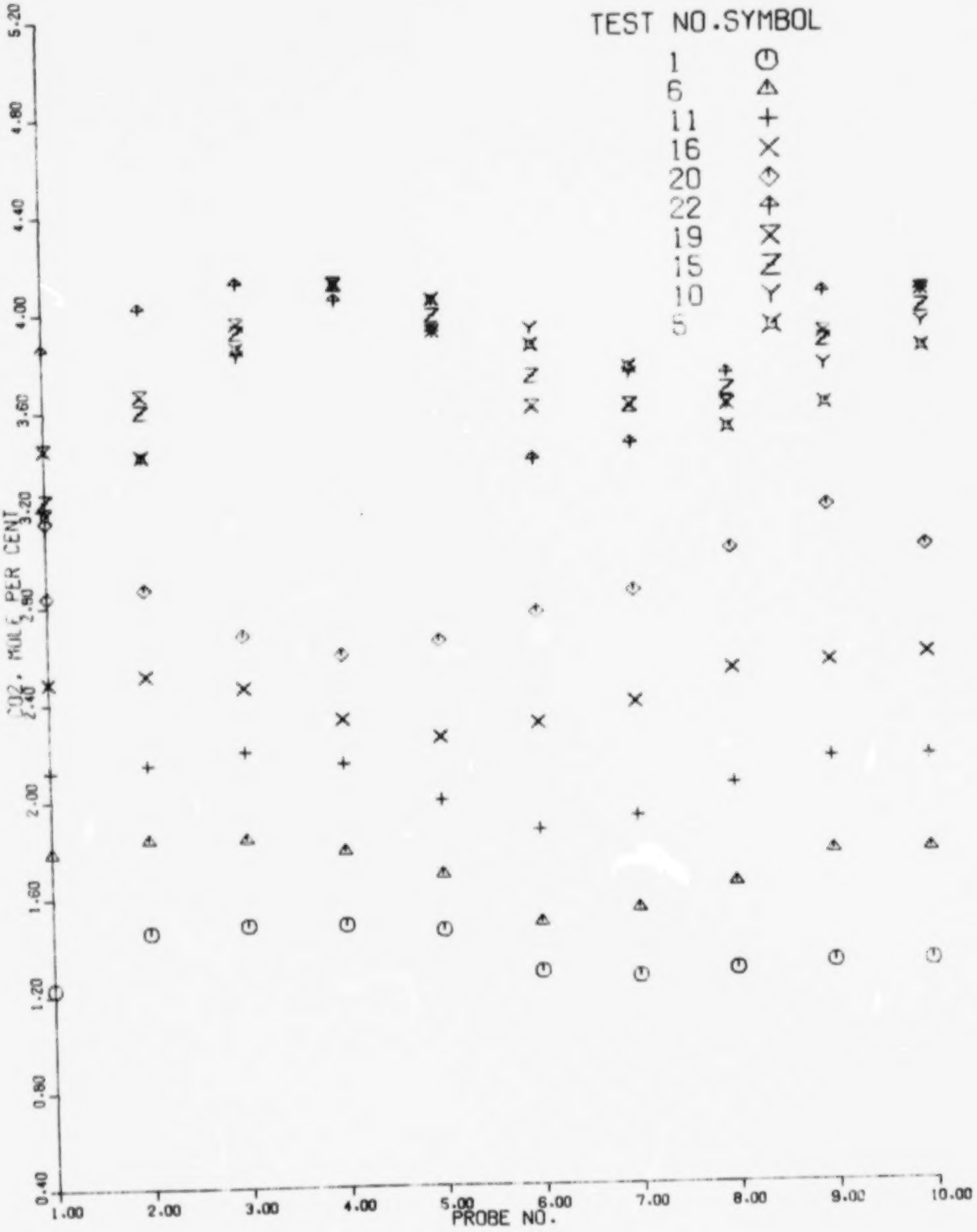

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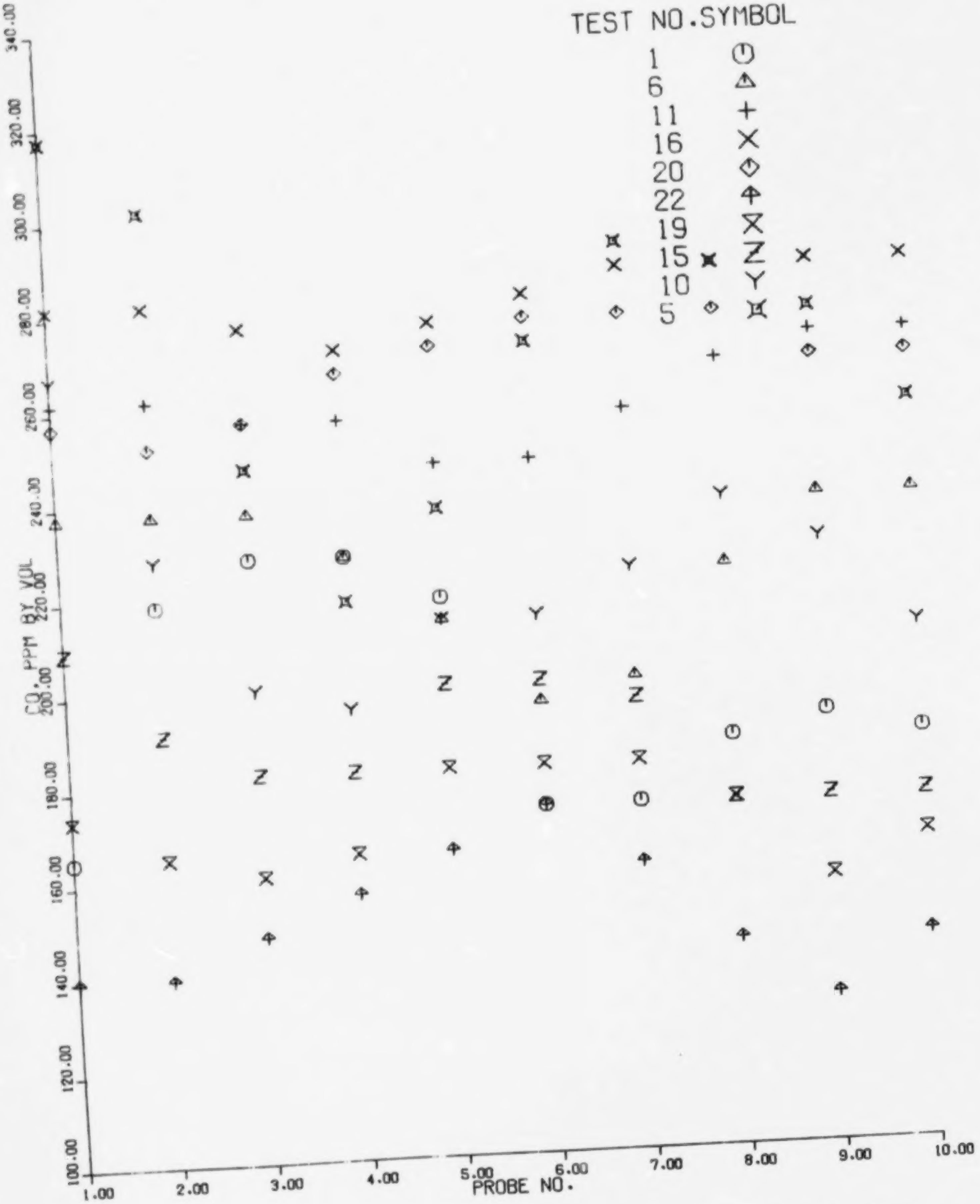

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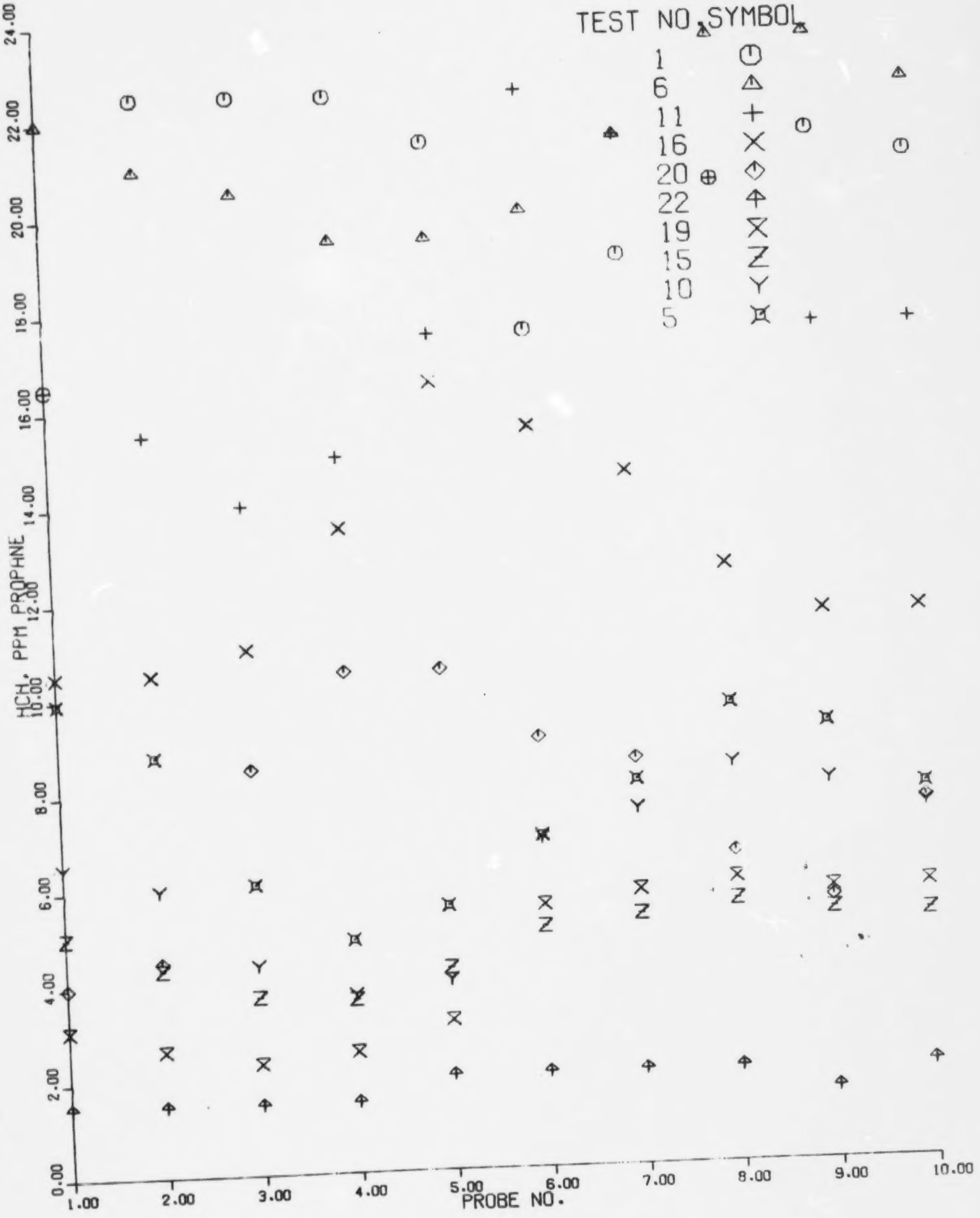

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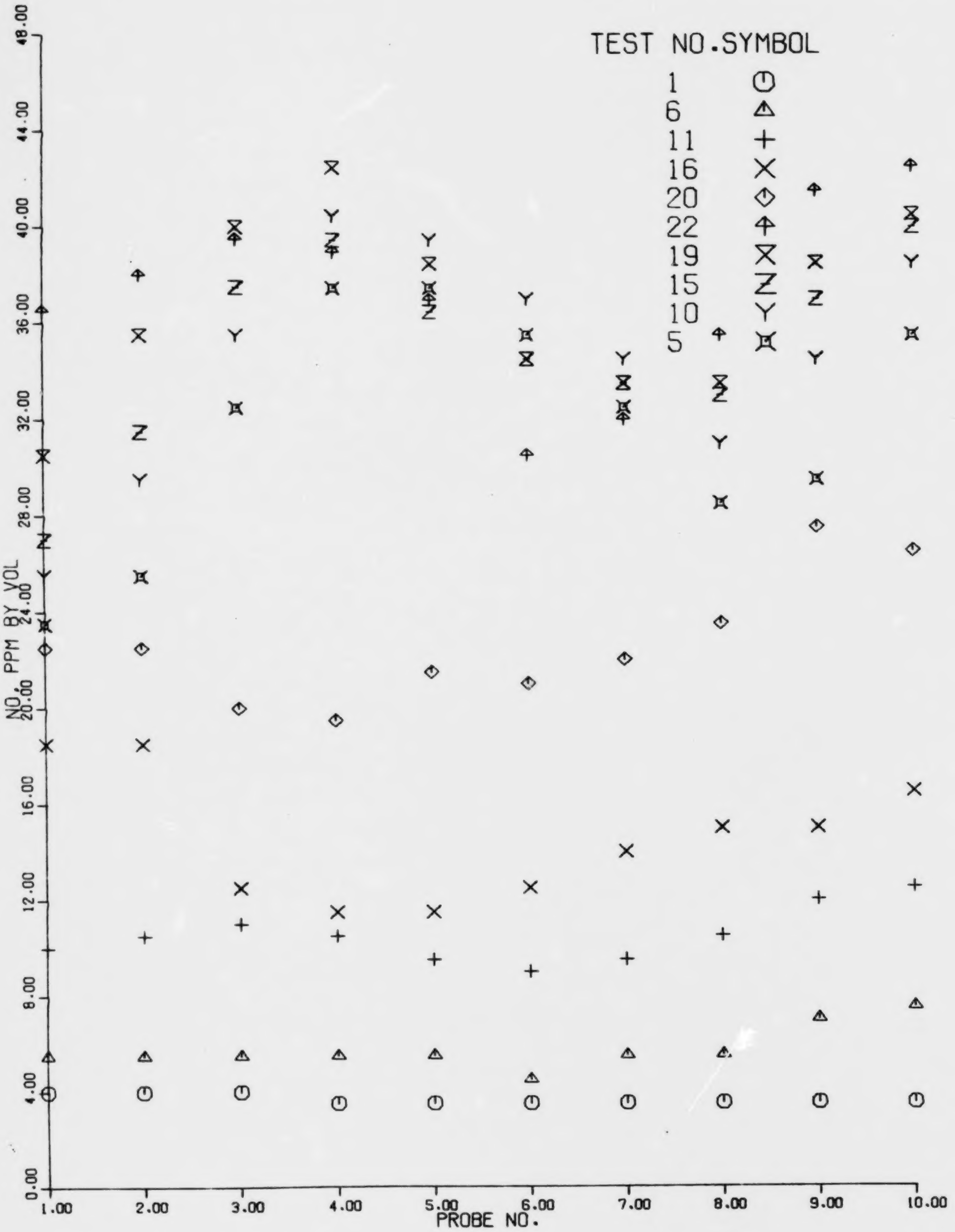

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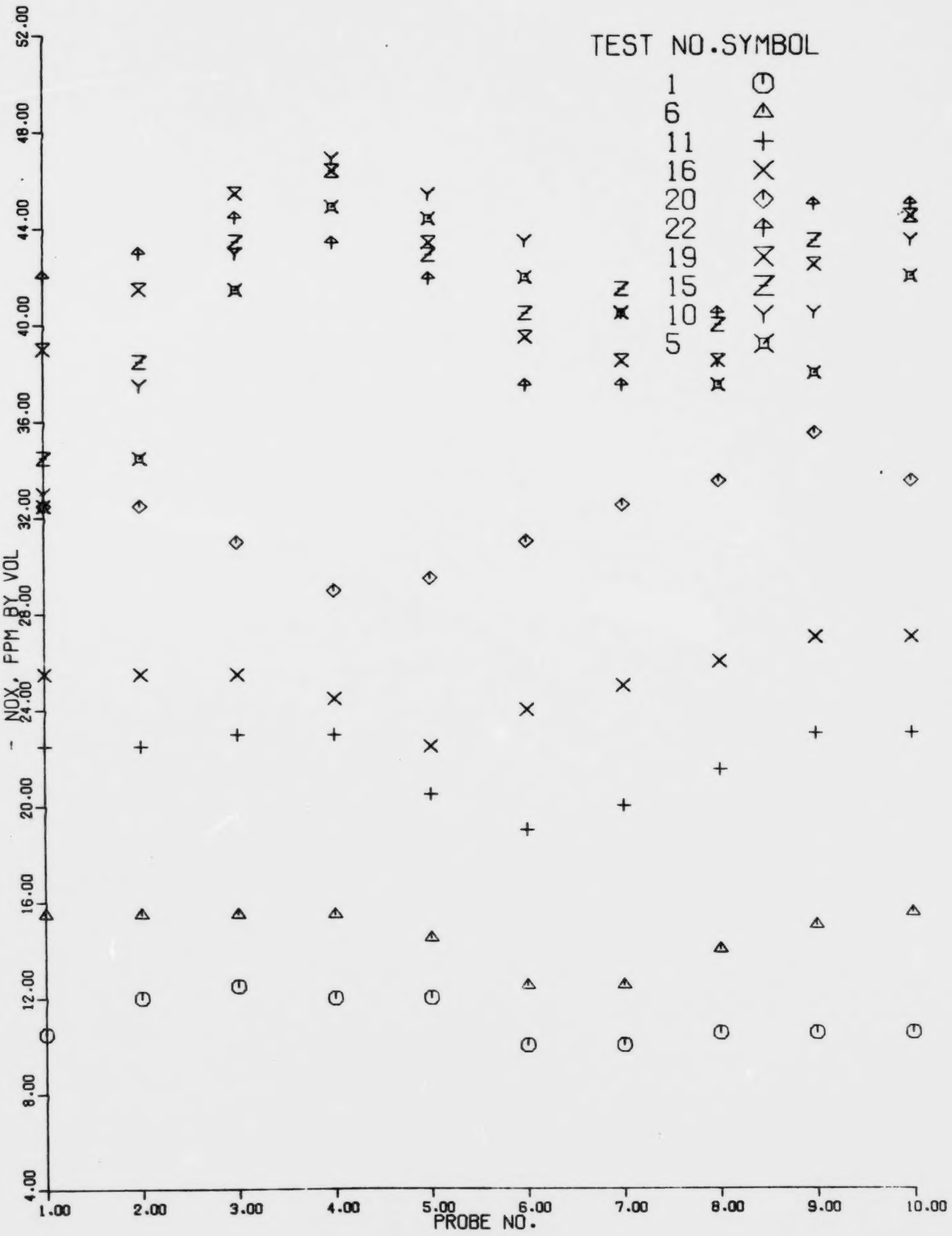

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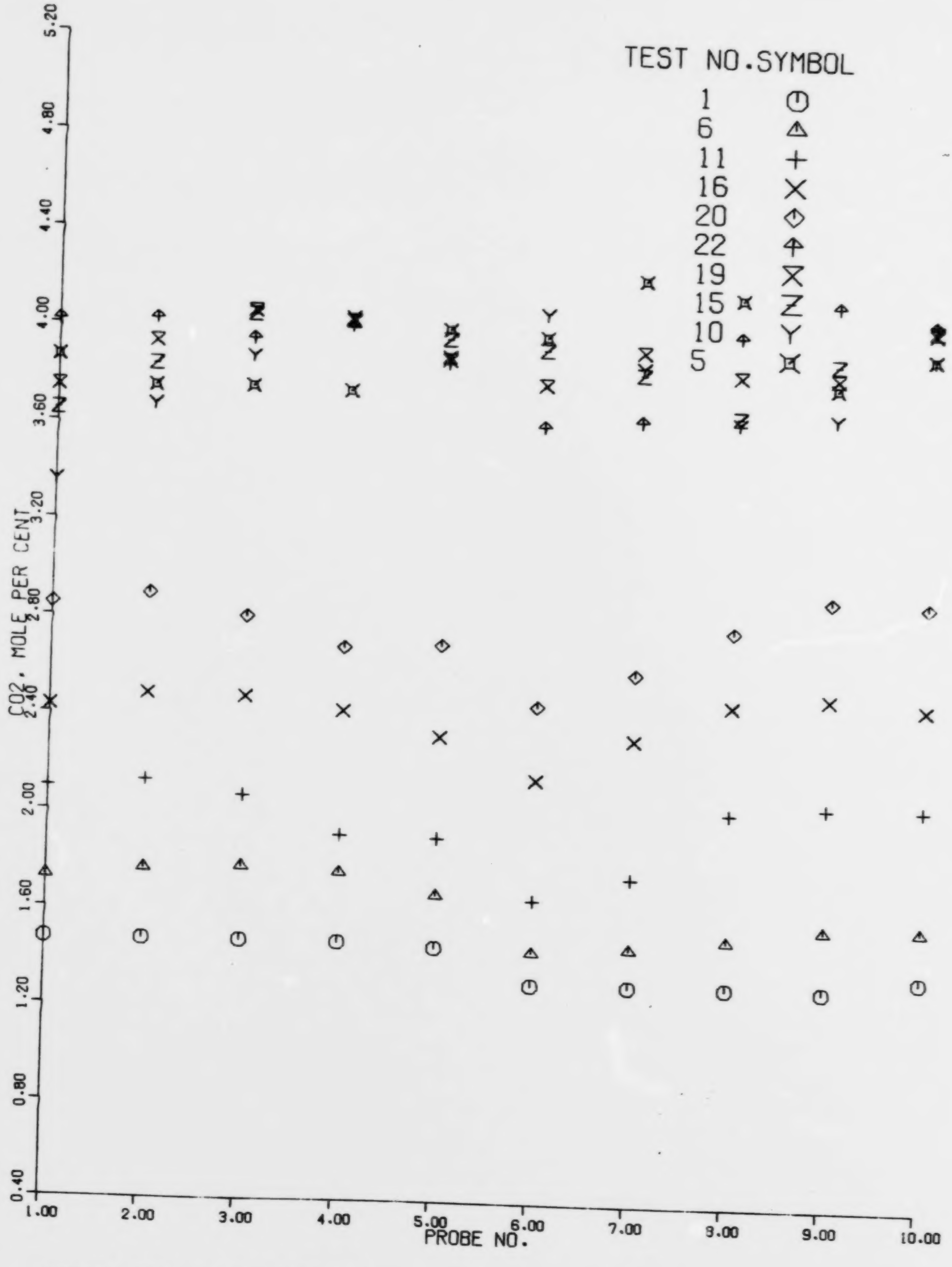
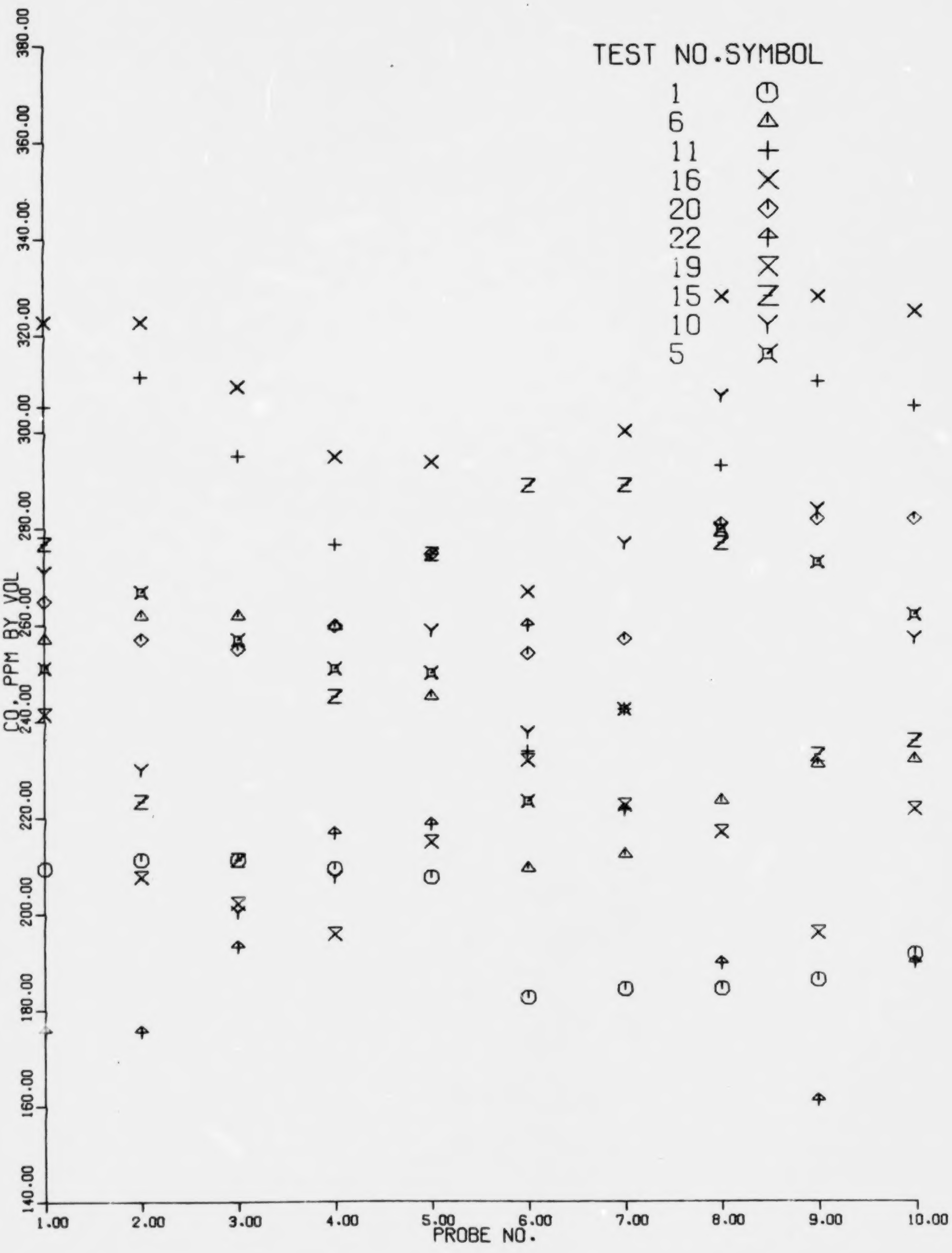


GTCP85-115 S/N P-18702, O/H, FUEL JP4 DATE 6/11/71 CELL D-111



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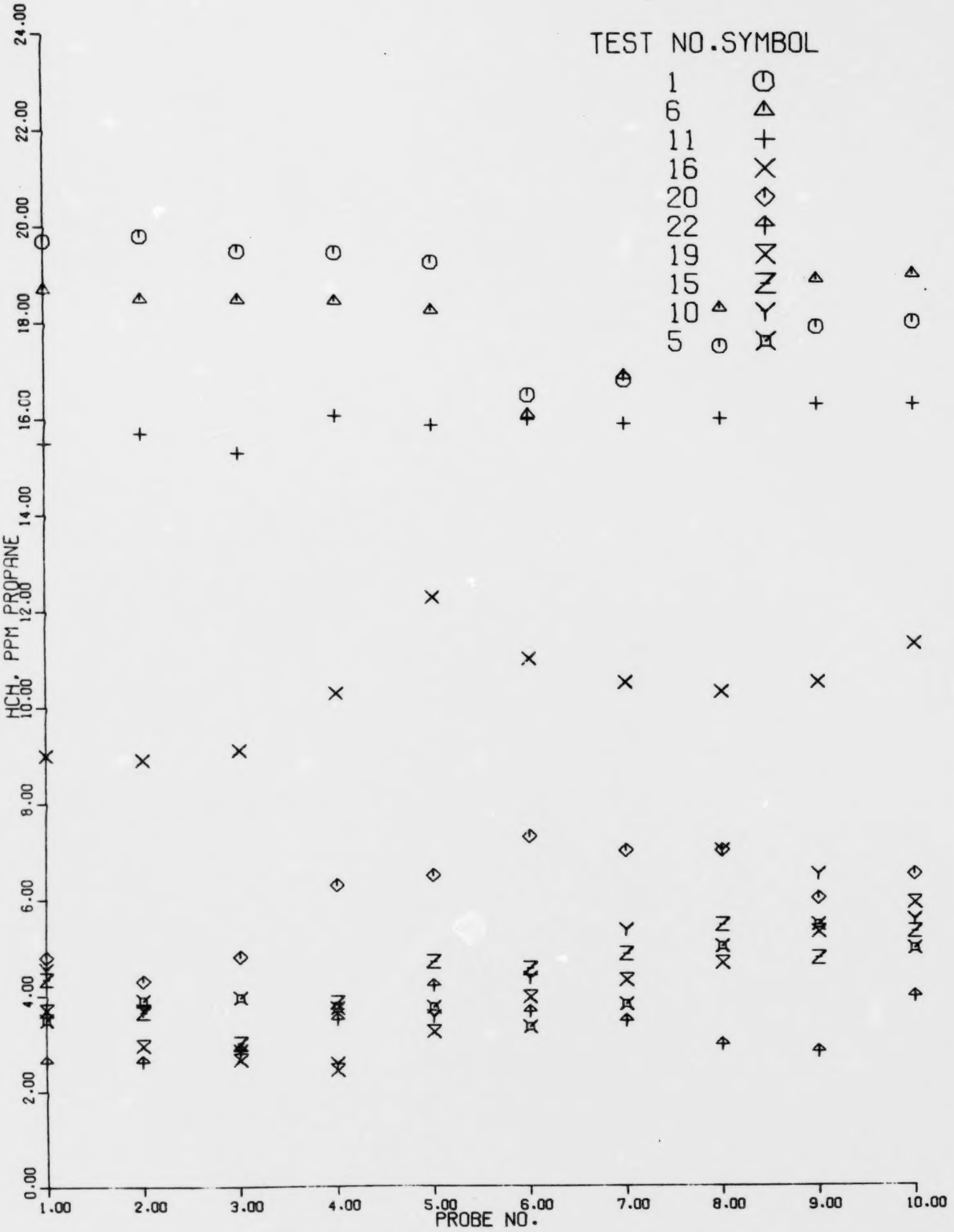

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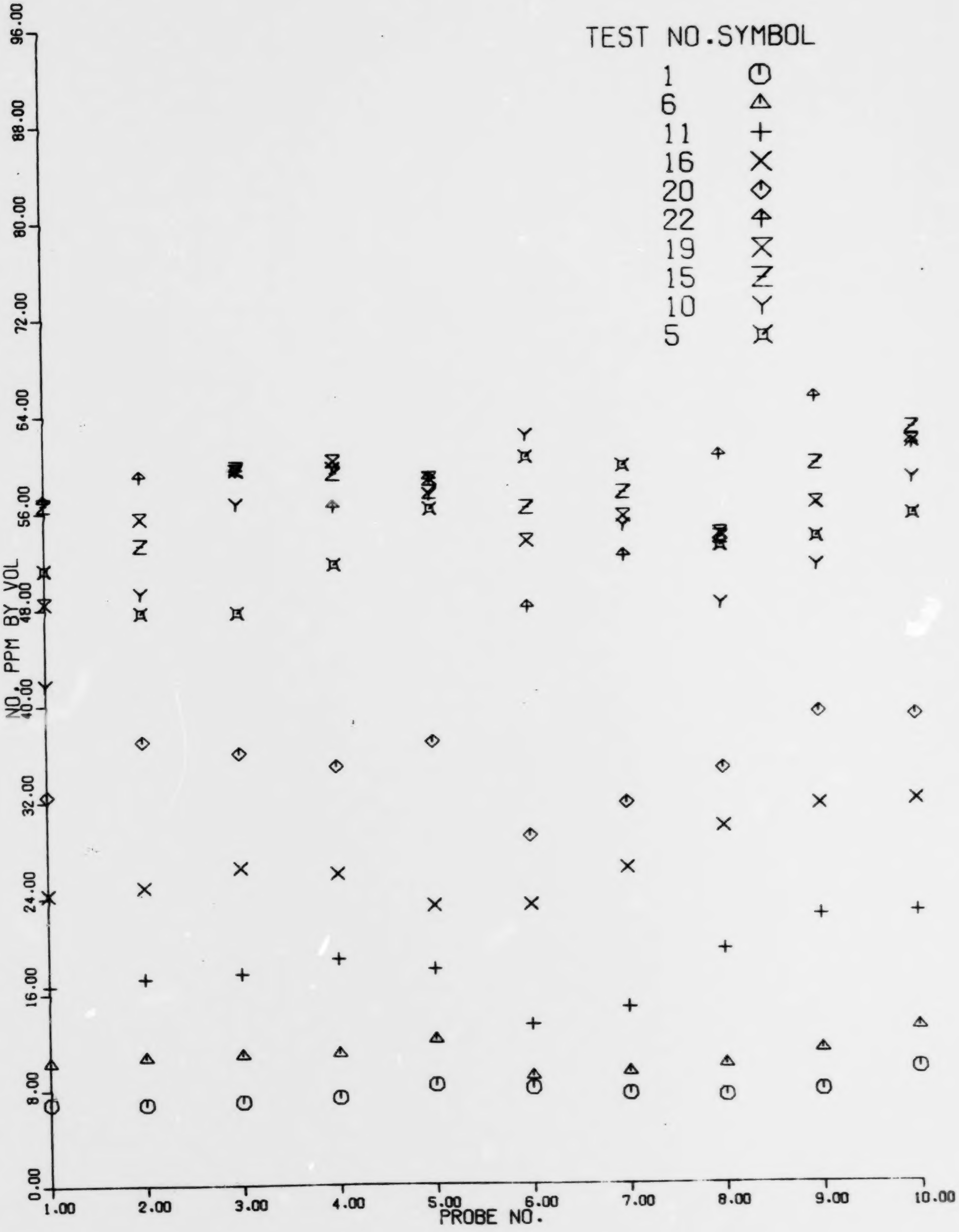

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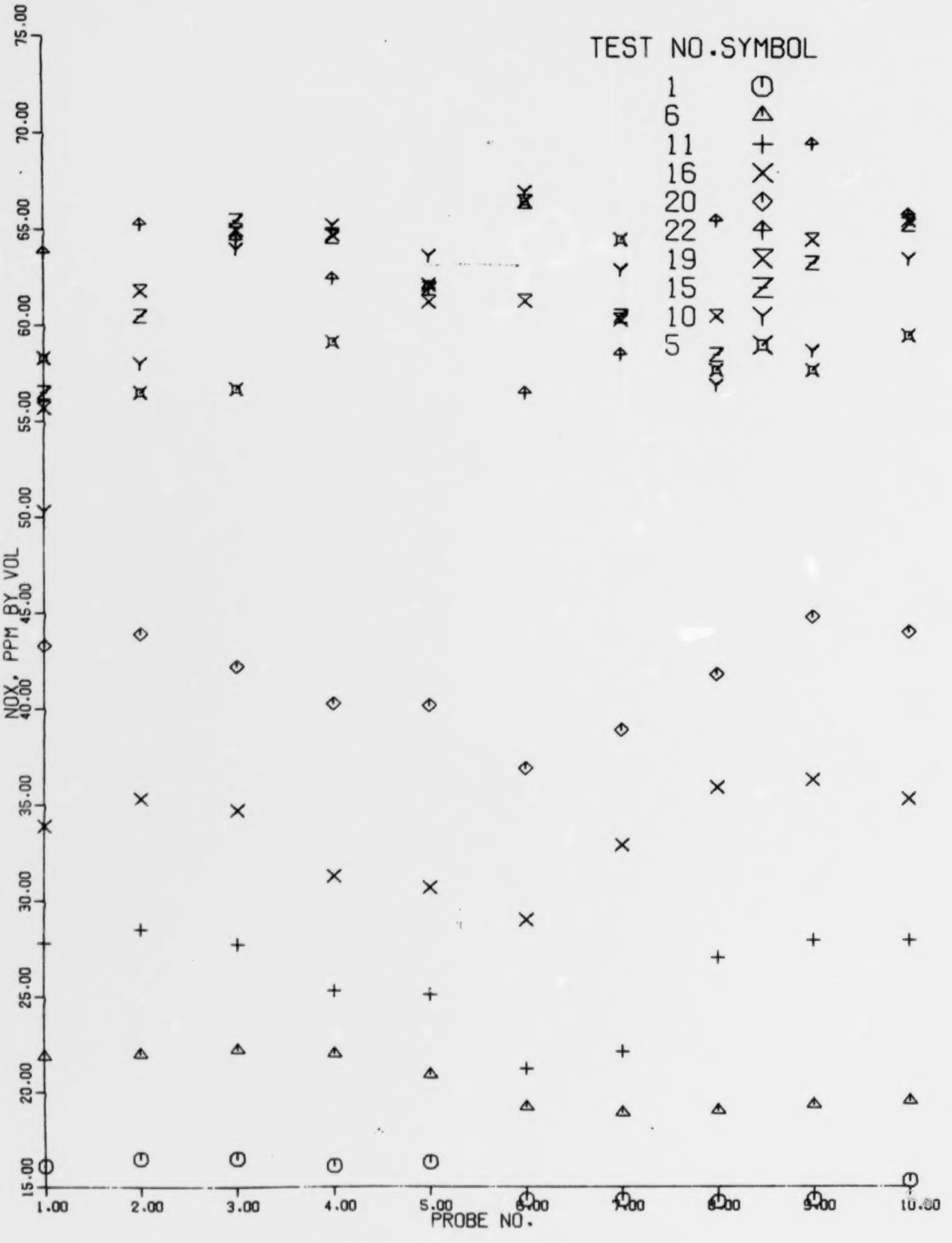

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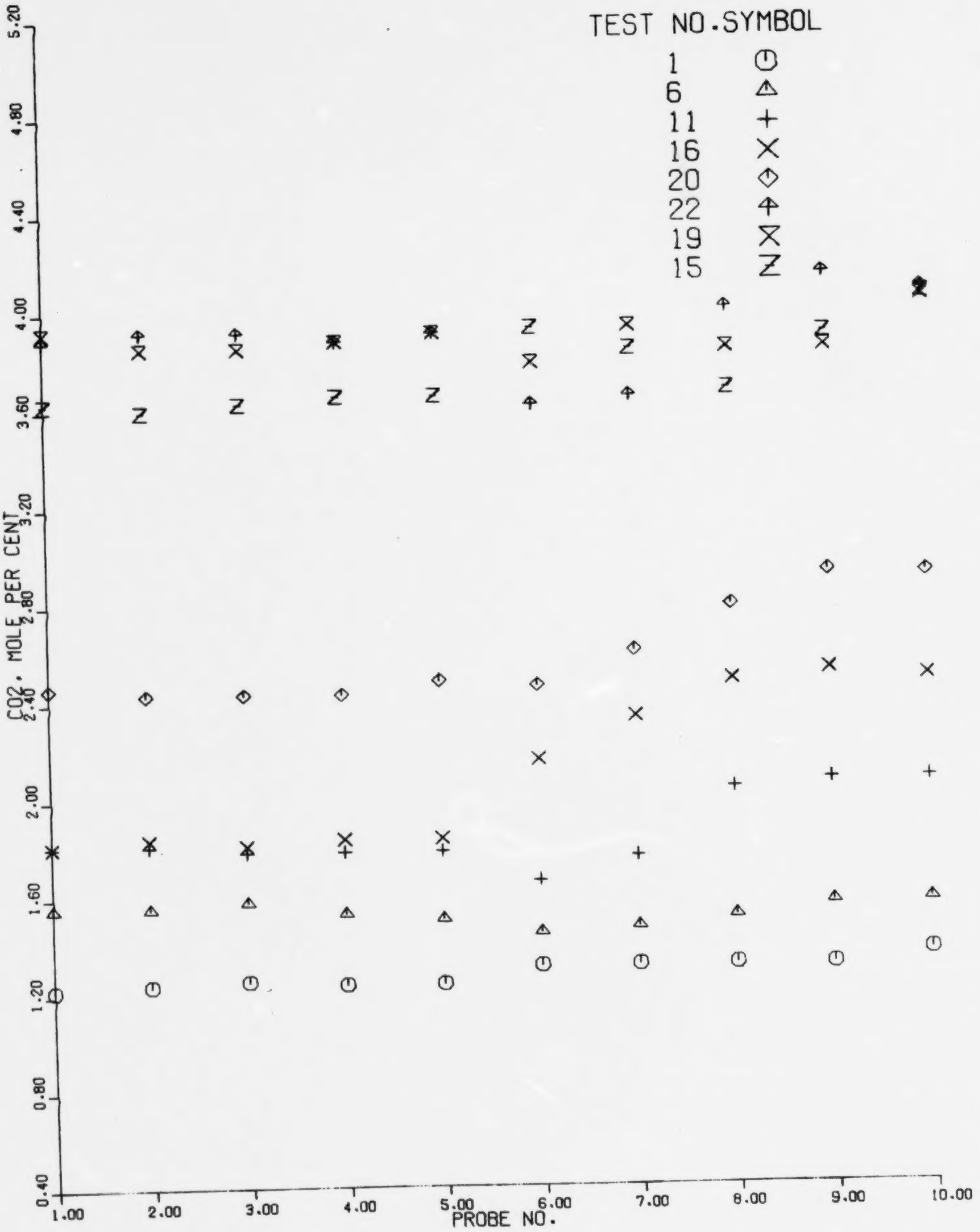
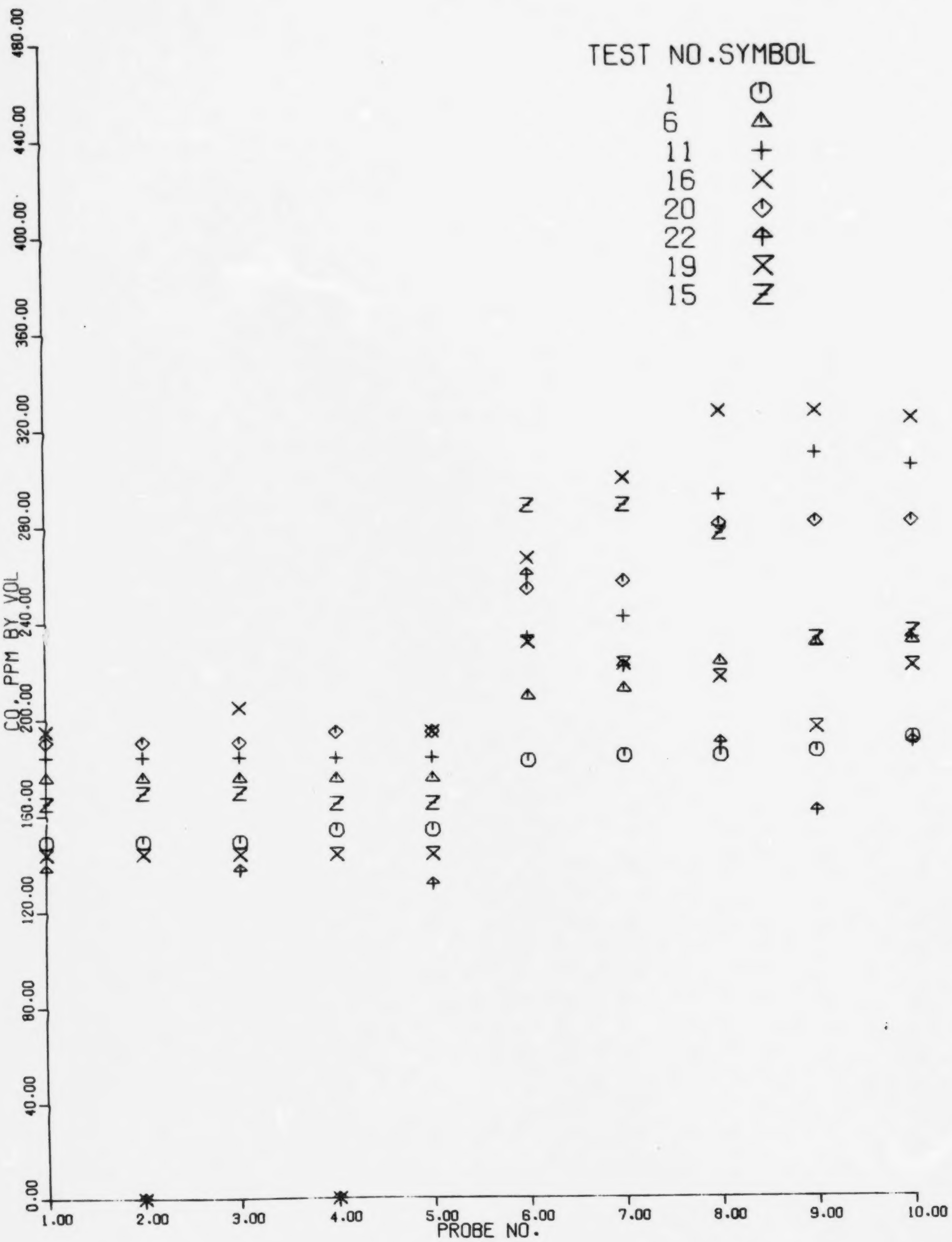


GTCP85-129 S/N P-34763, O/H, FUEL JP4, DATE 4/28/71 CELL C-102



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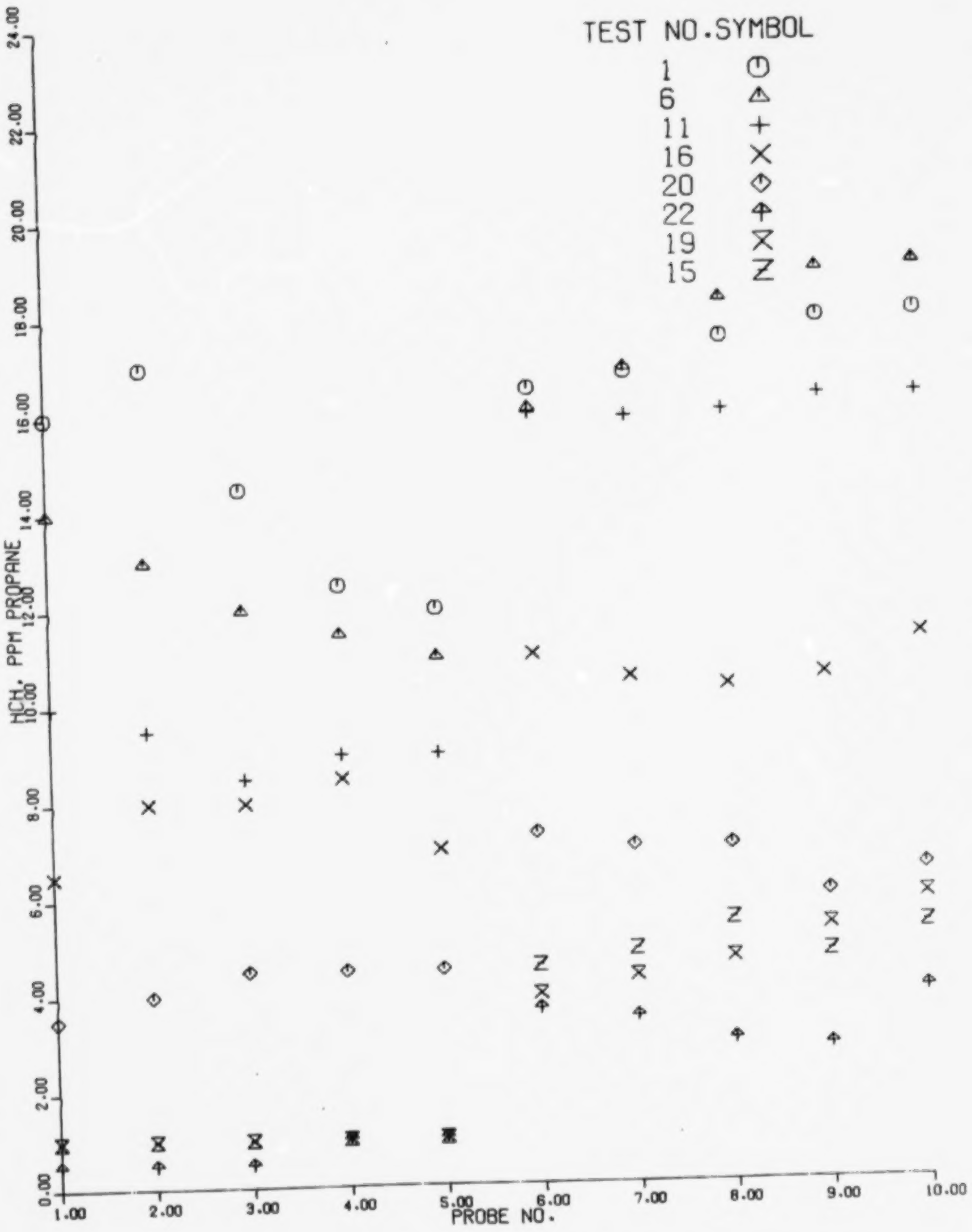

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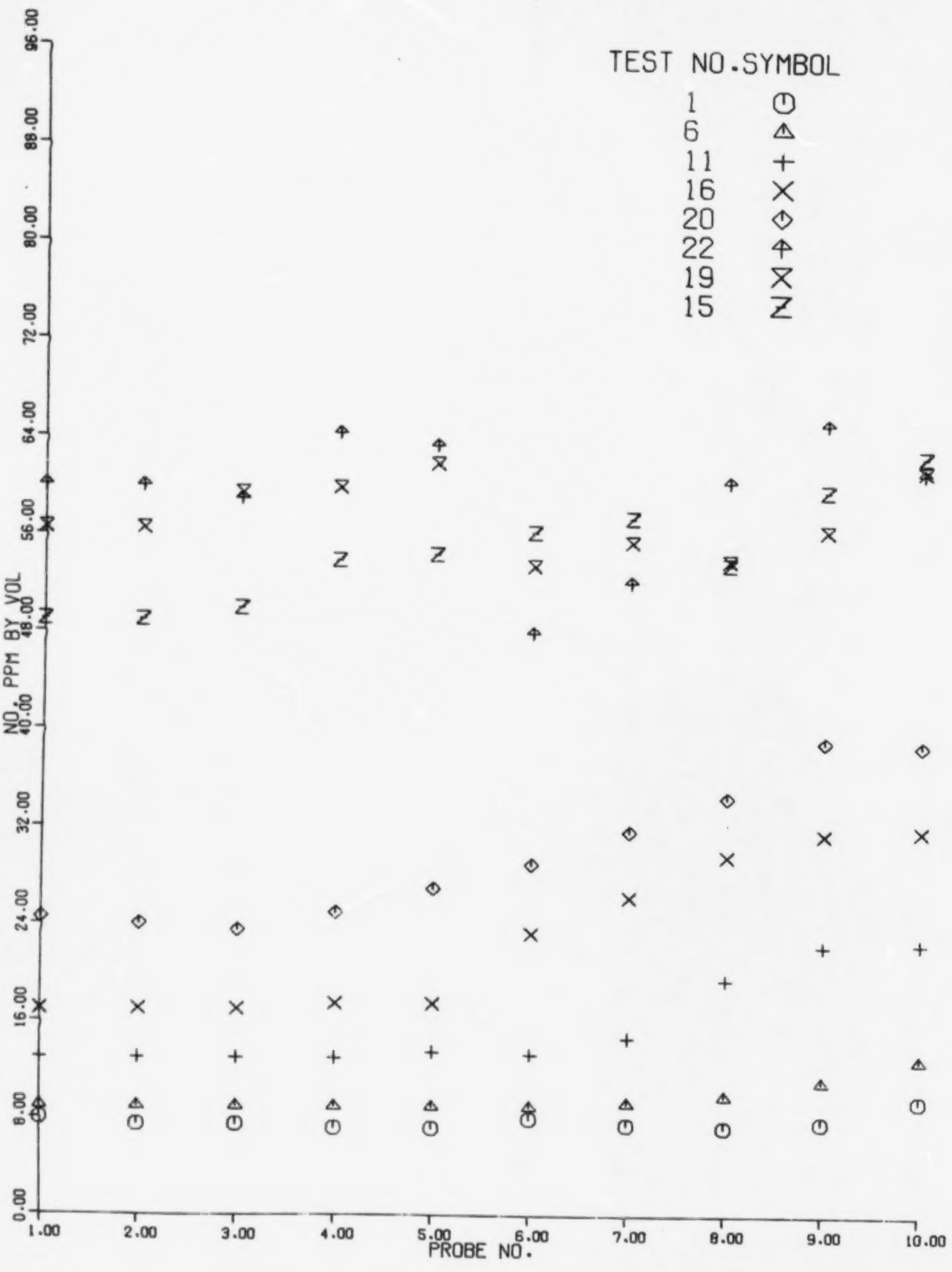

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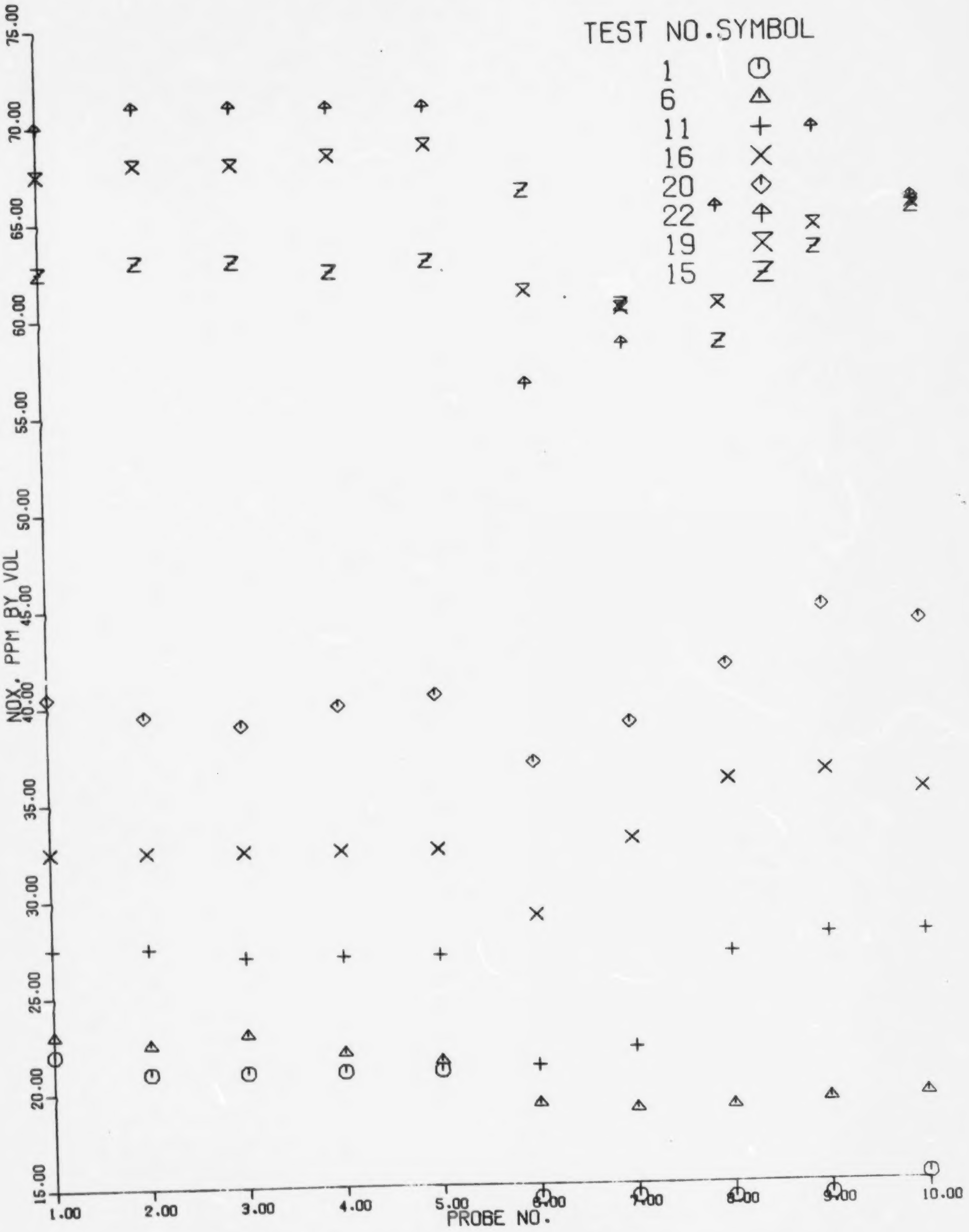

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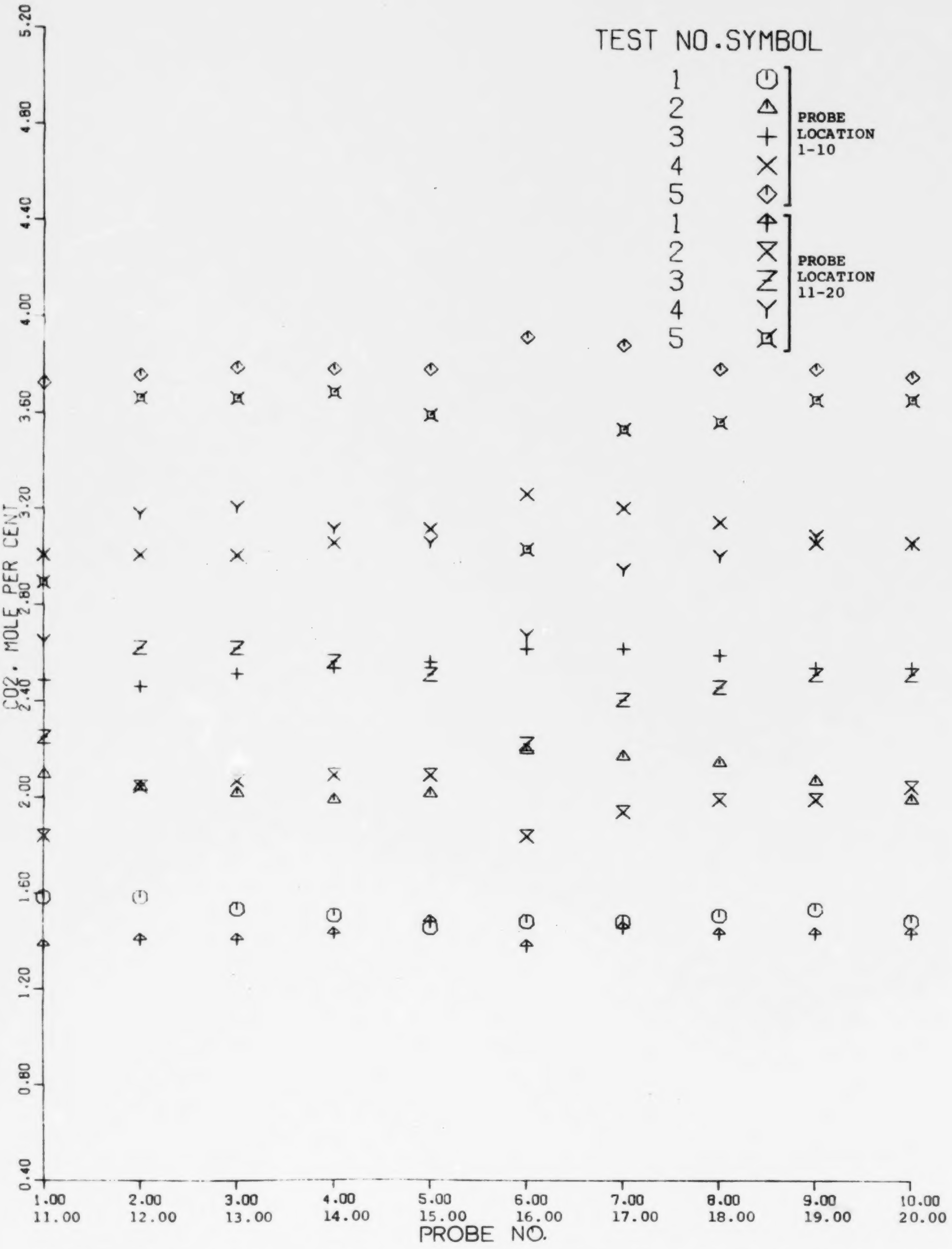
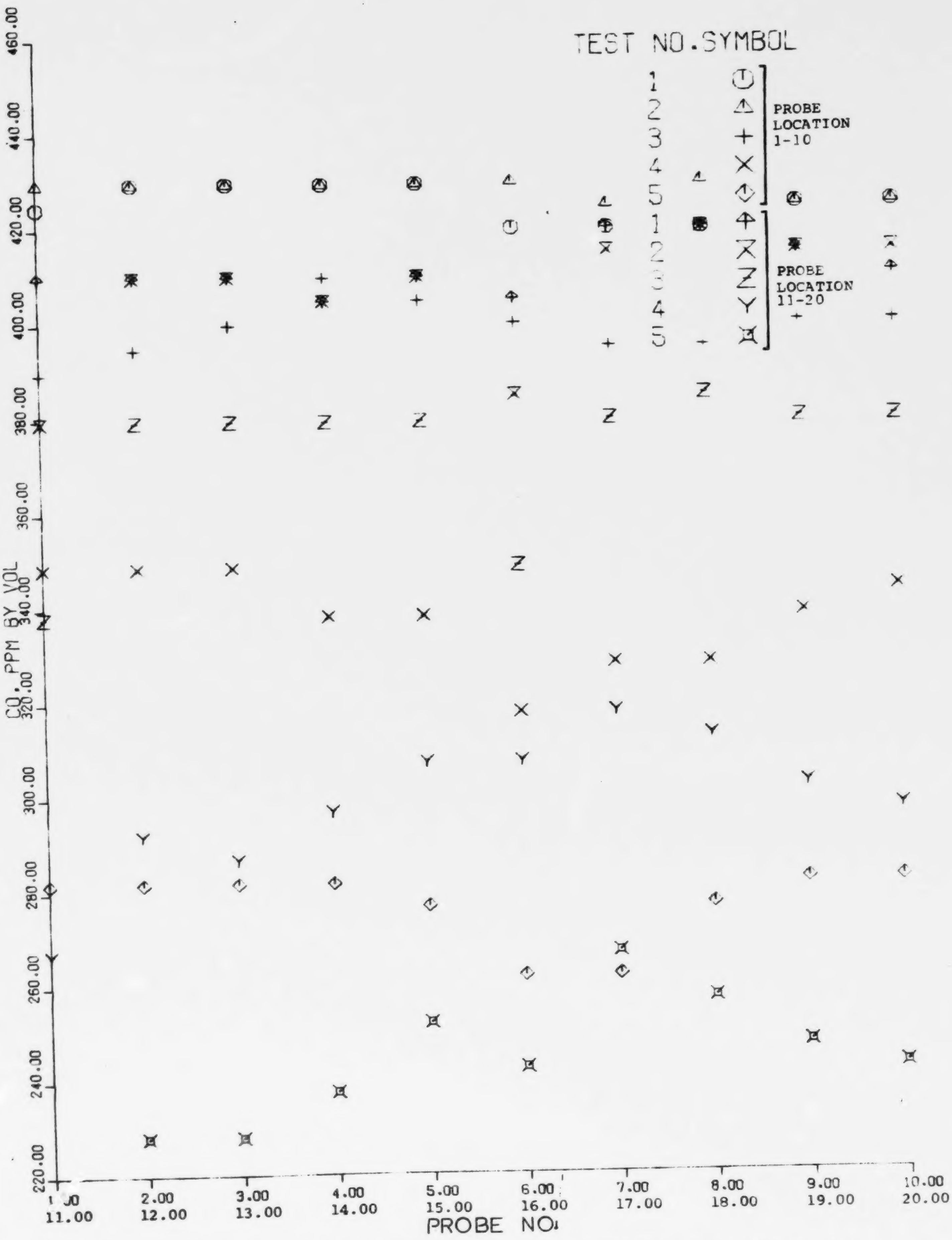
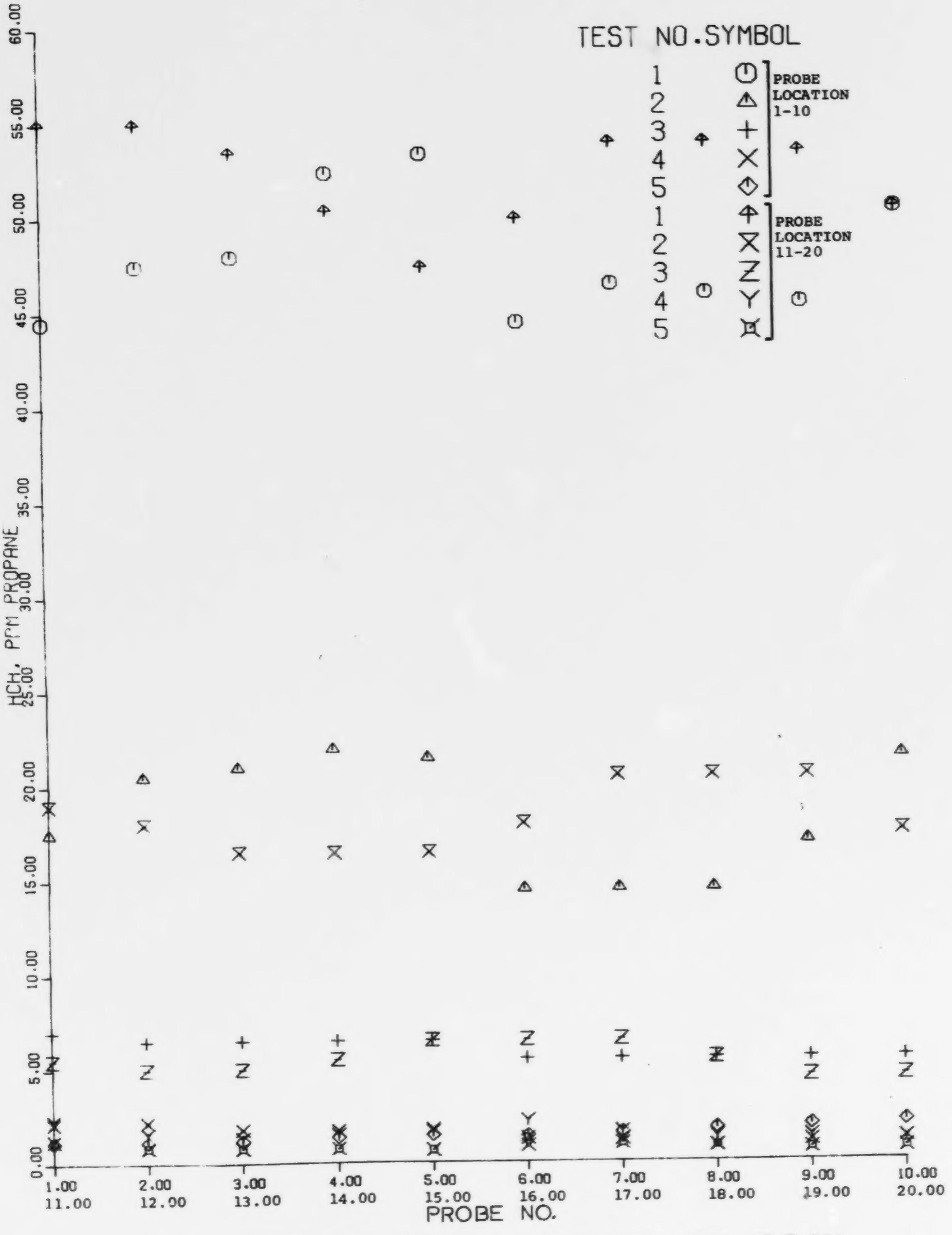


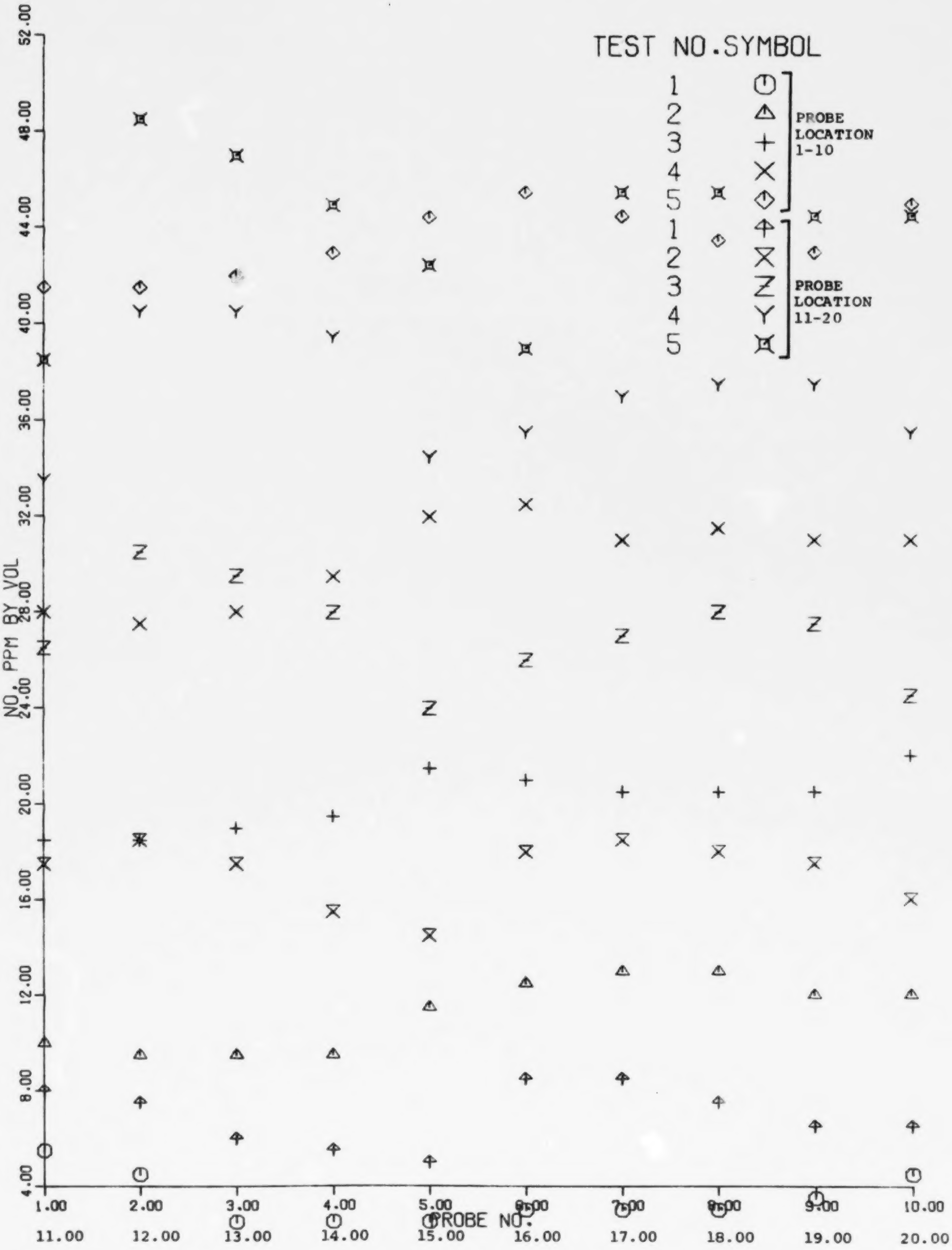
GTC85-90, S/N P-5786, O/H, FUEL JP5, DATE 5/18/71, CELL NO.D-111



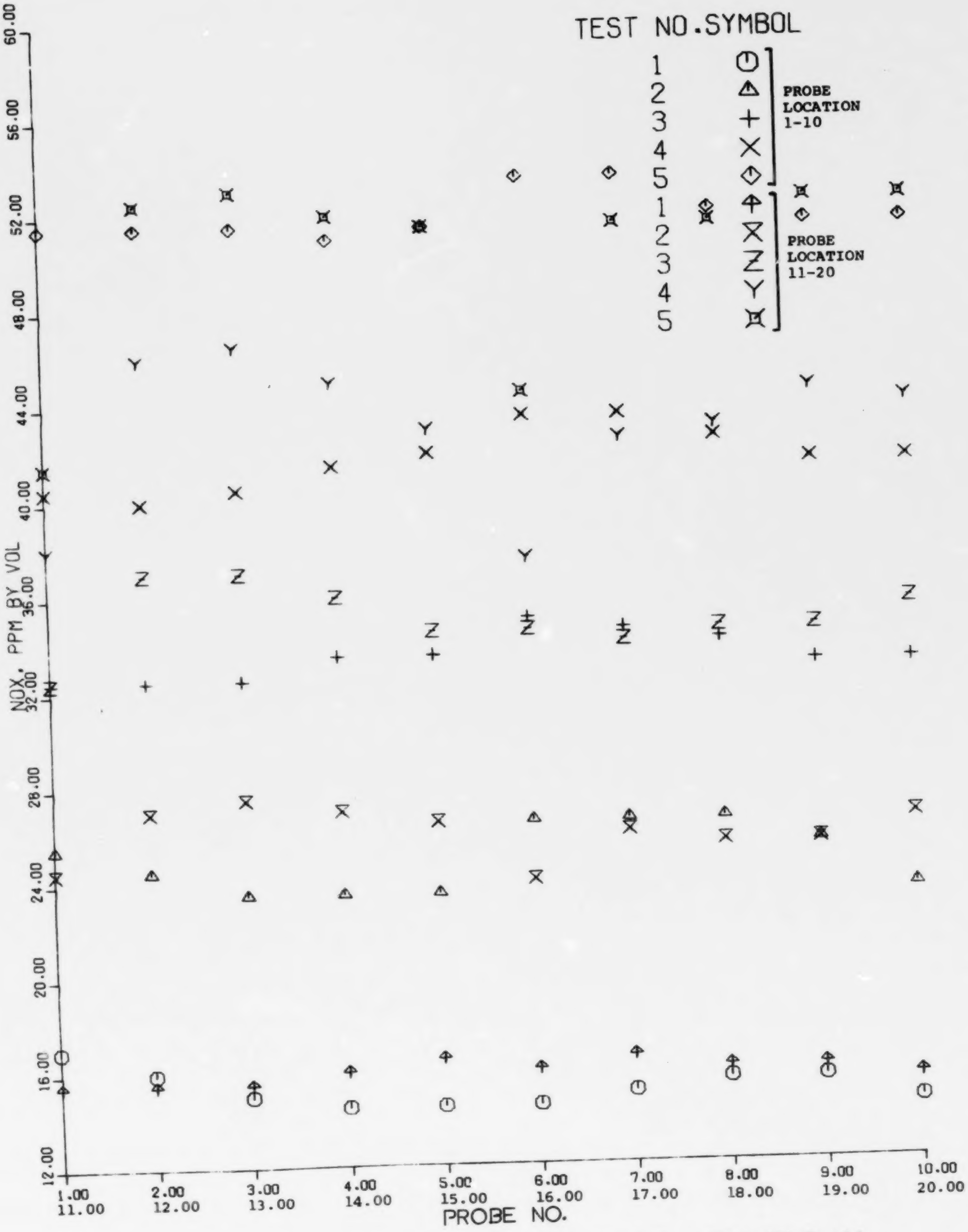
GTC85-90, S/N P-5786, O/H, FUEL JP5, DATE 5/18/71, CELL NO.D-111



GTC85-90. S/N P-5786. O/H. FUEL JP5. DATE 5/18/71. CELL NO.D-111



GTC85-90, S/N P-5786, O/H, FUEL JP5, DATE 5/18/71, CELL NO.D-111



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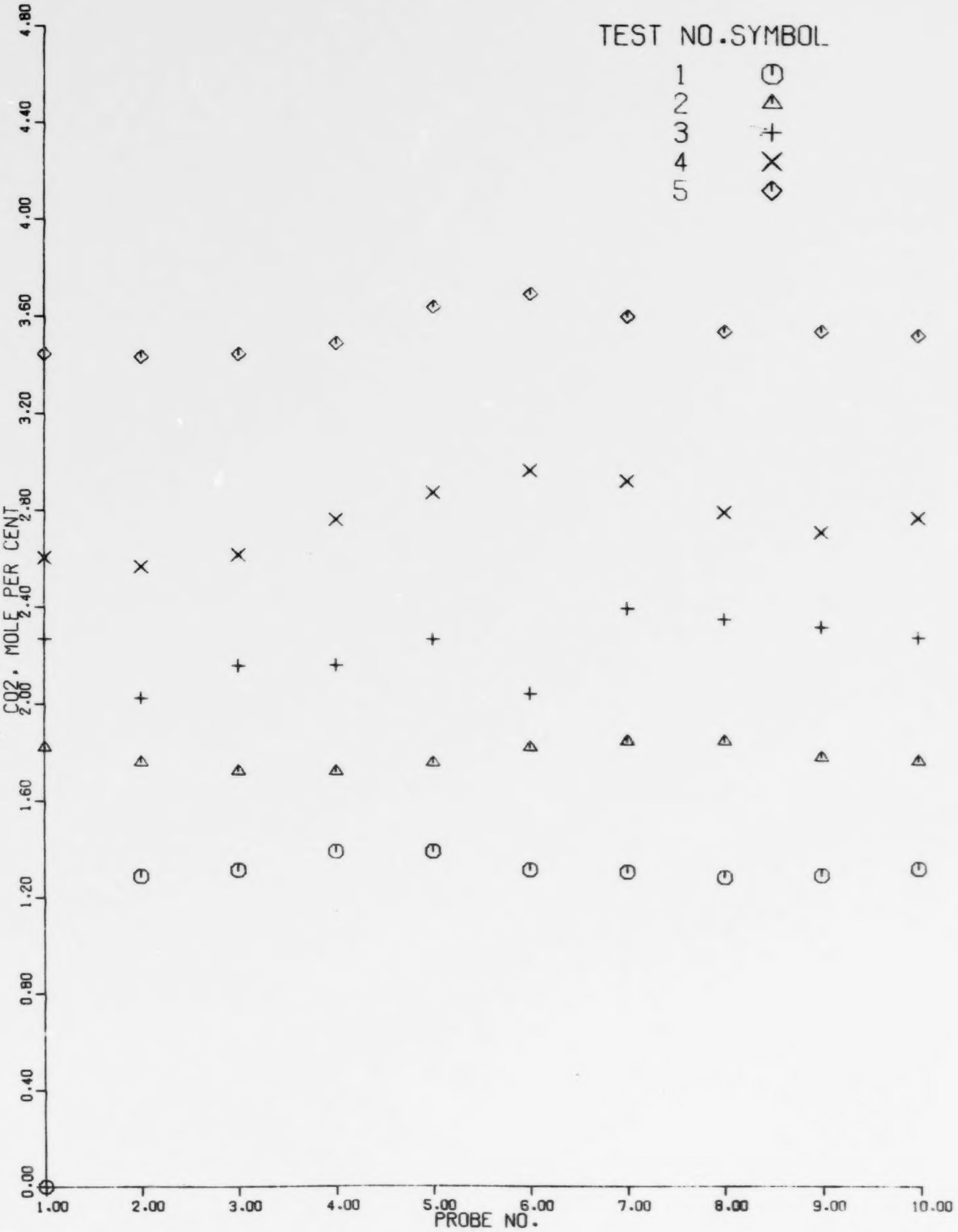

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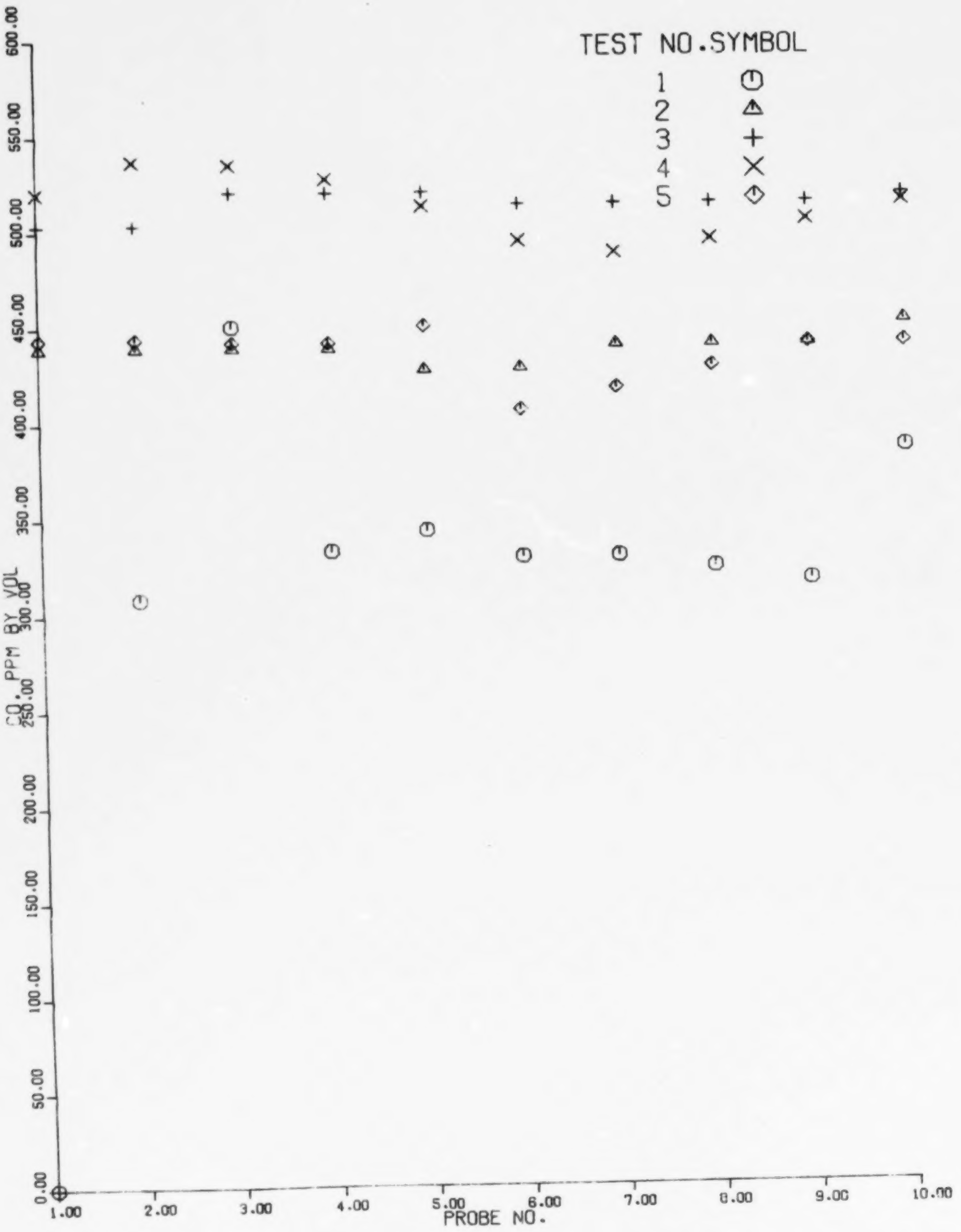

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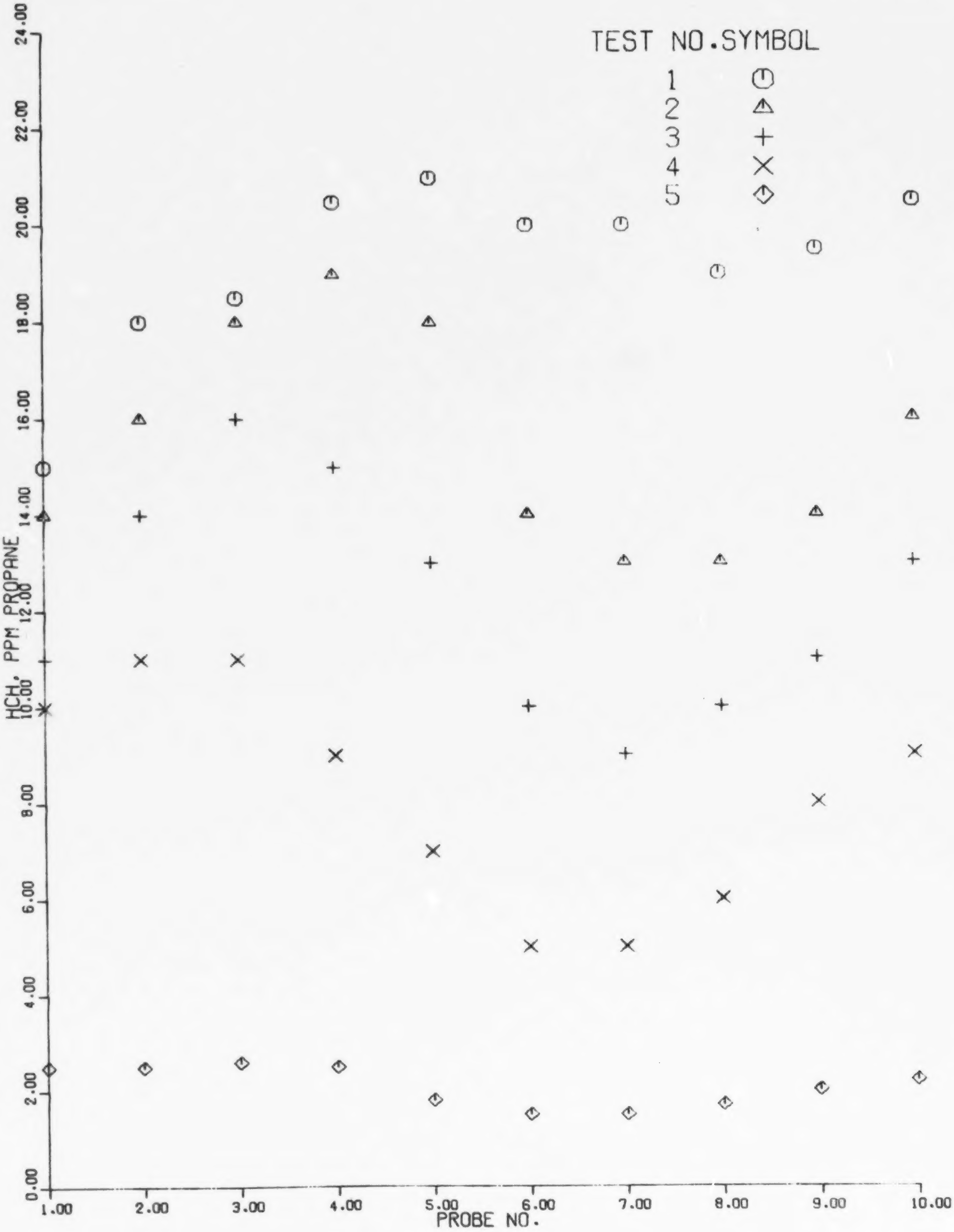

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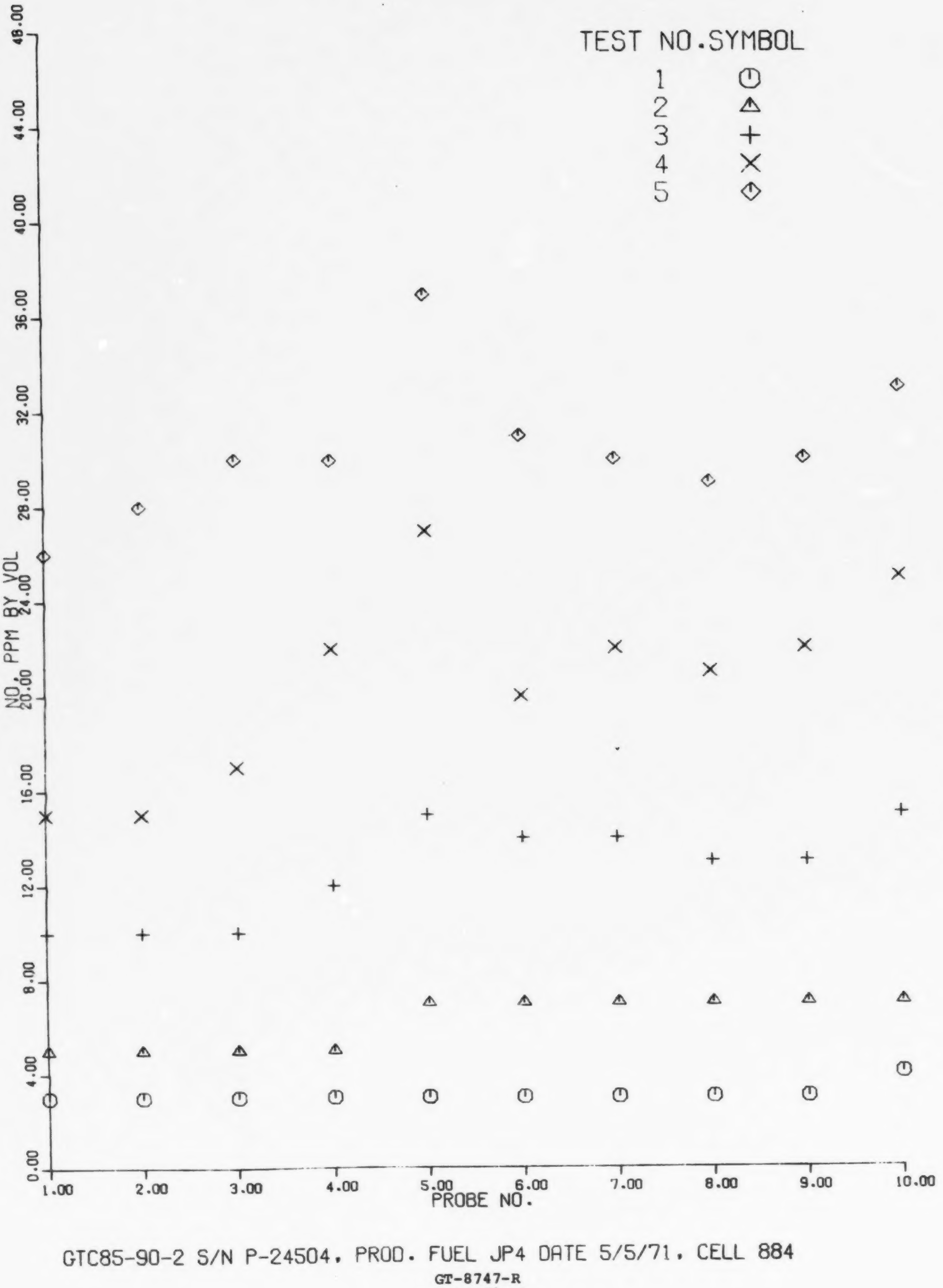

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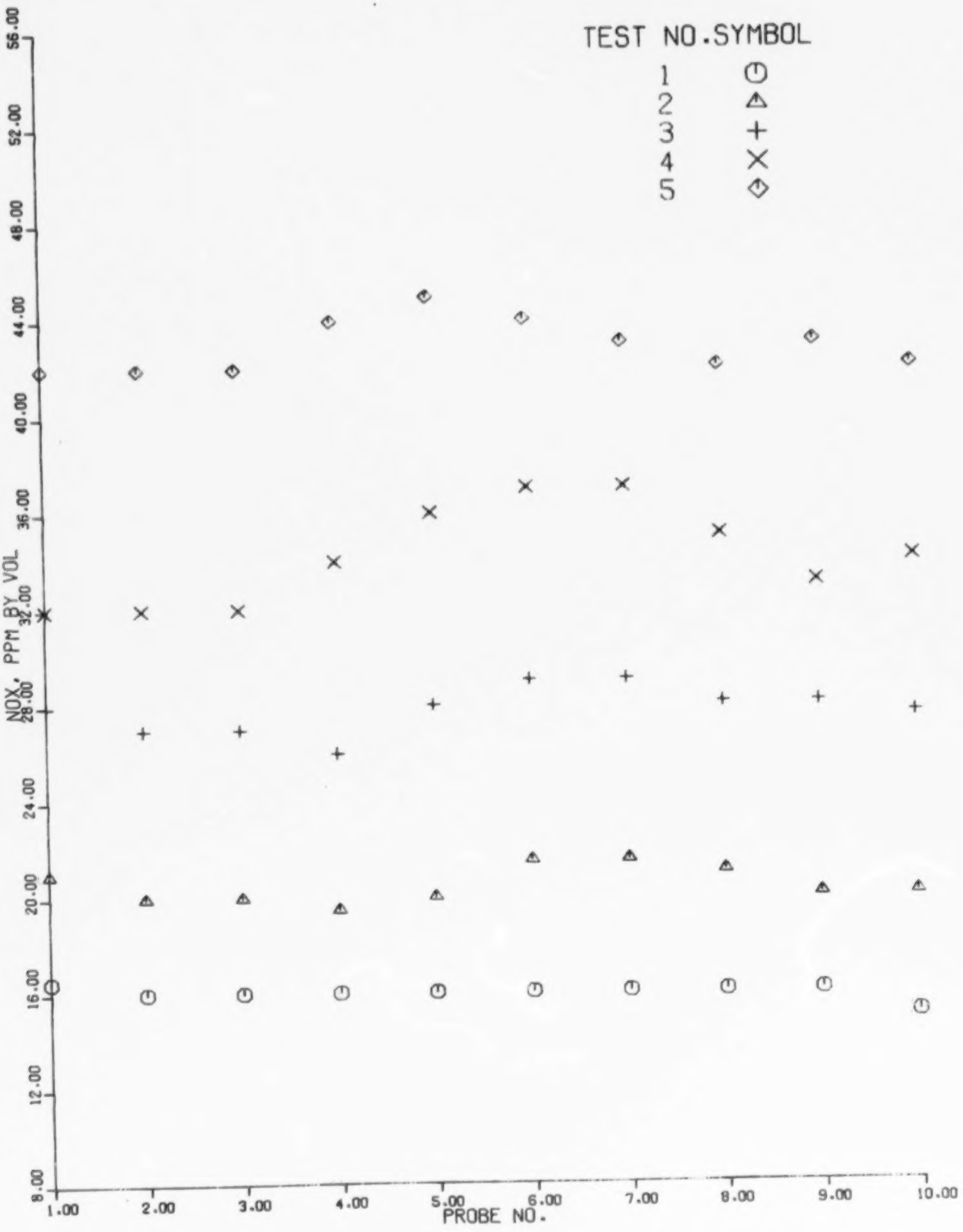

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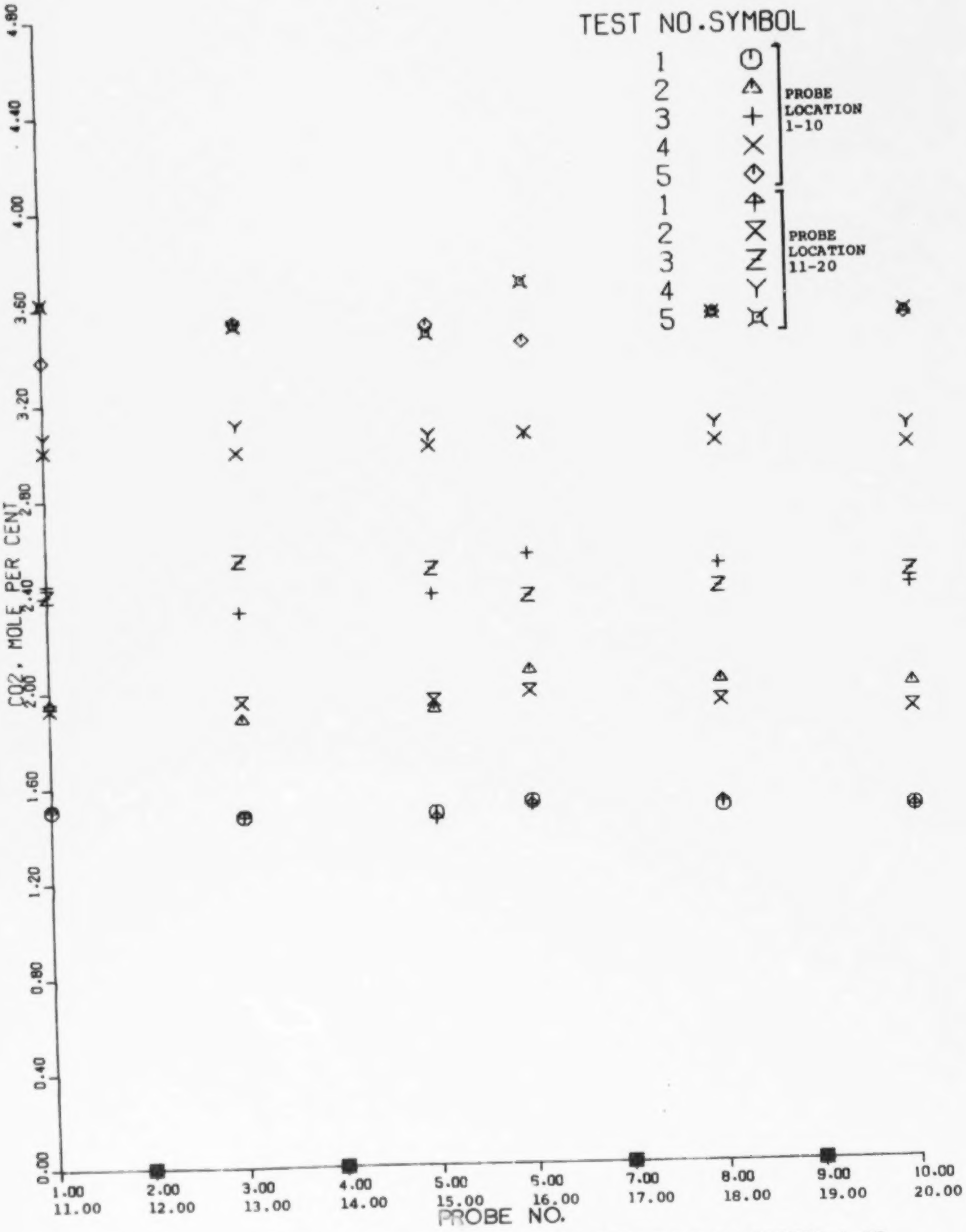

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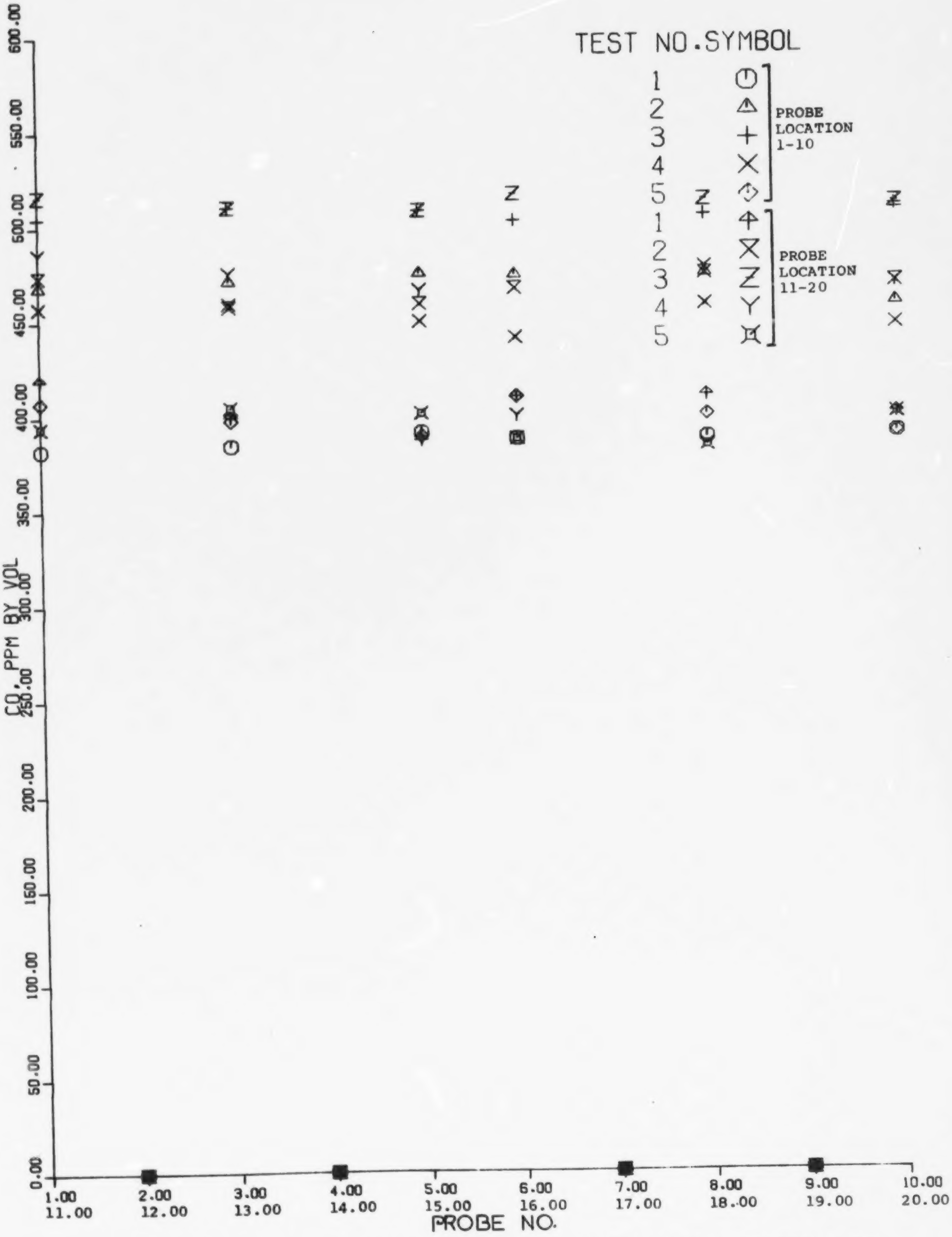

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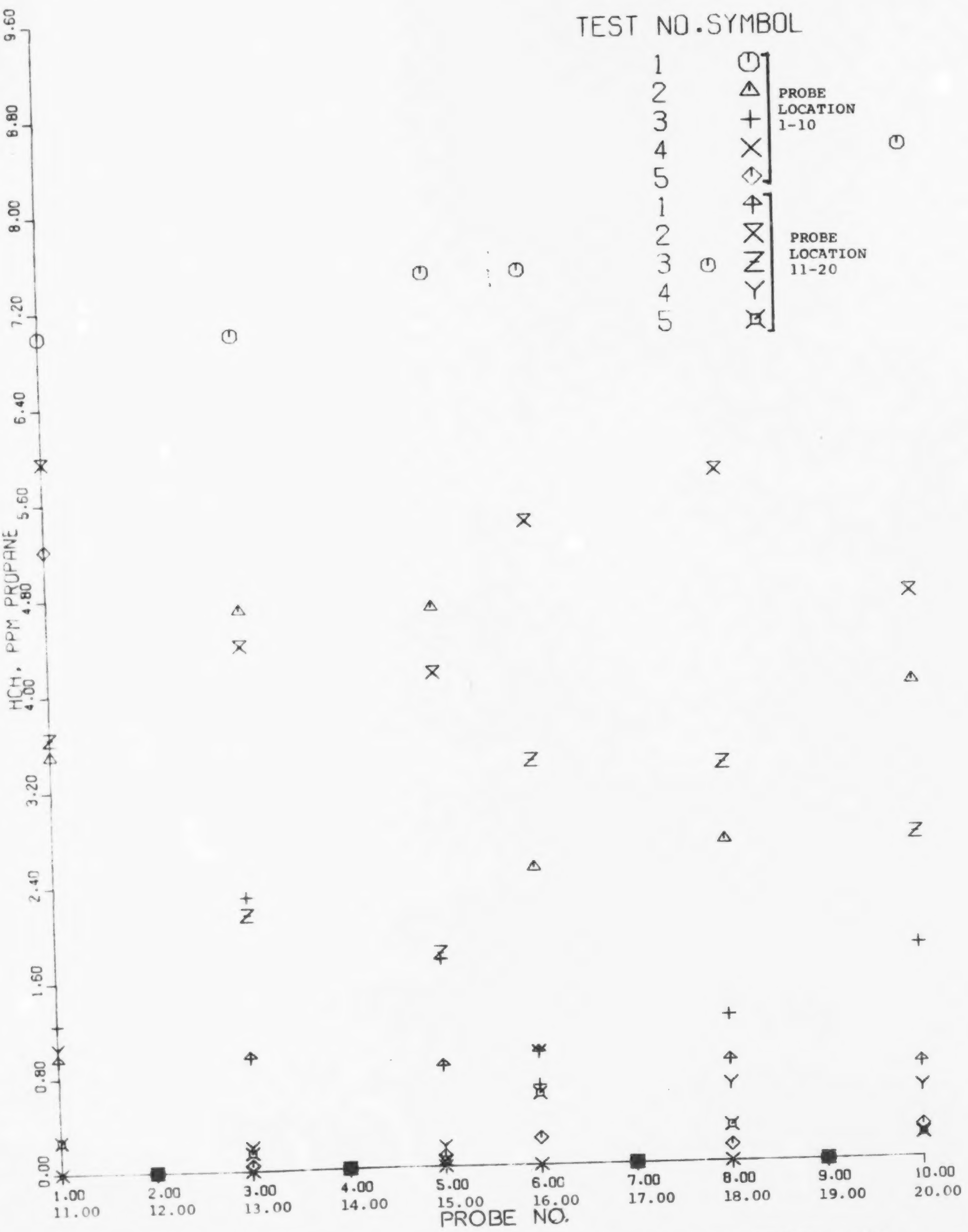

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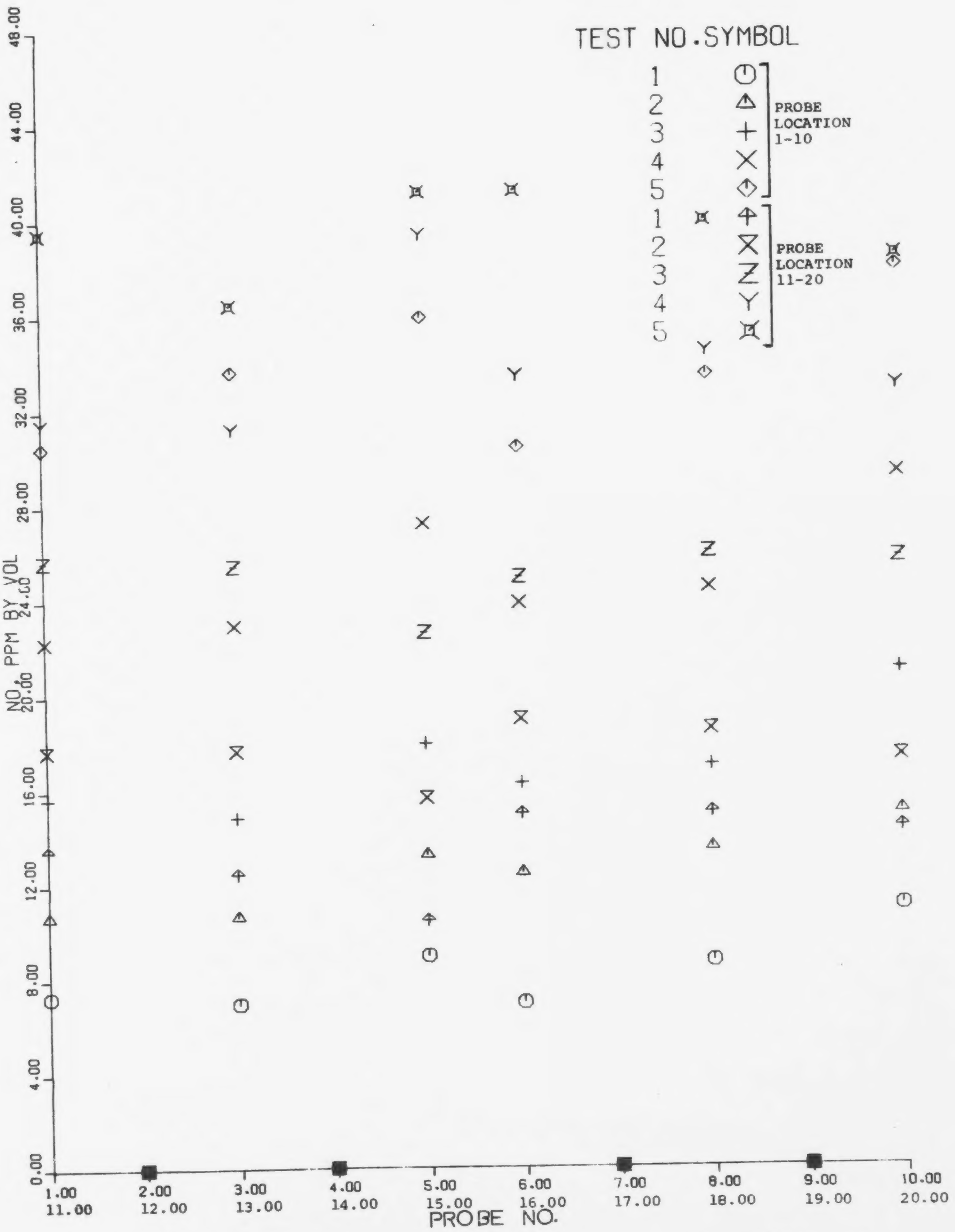

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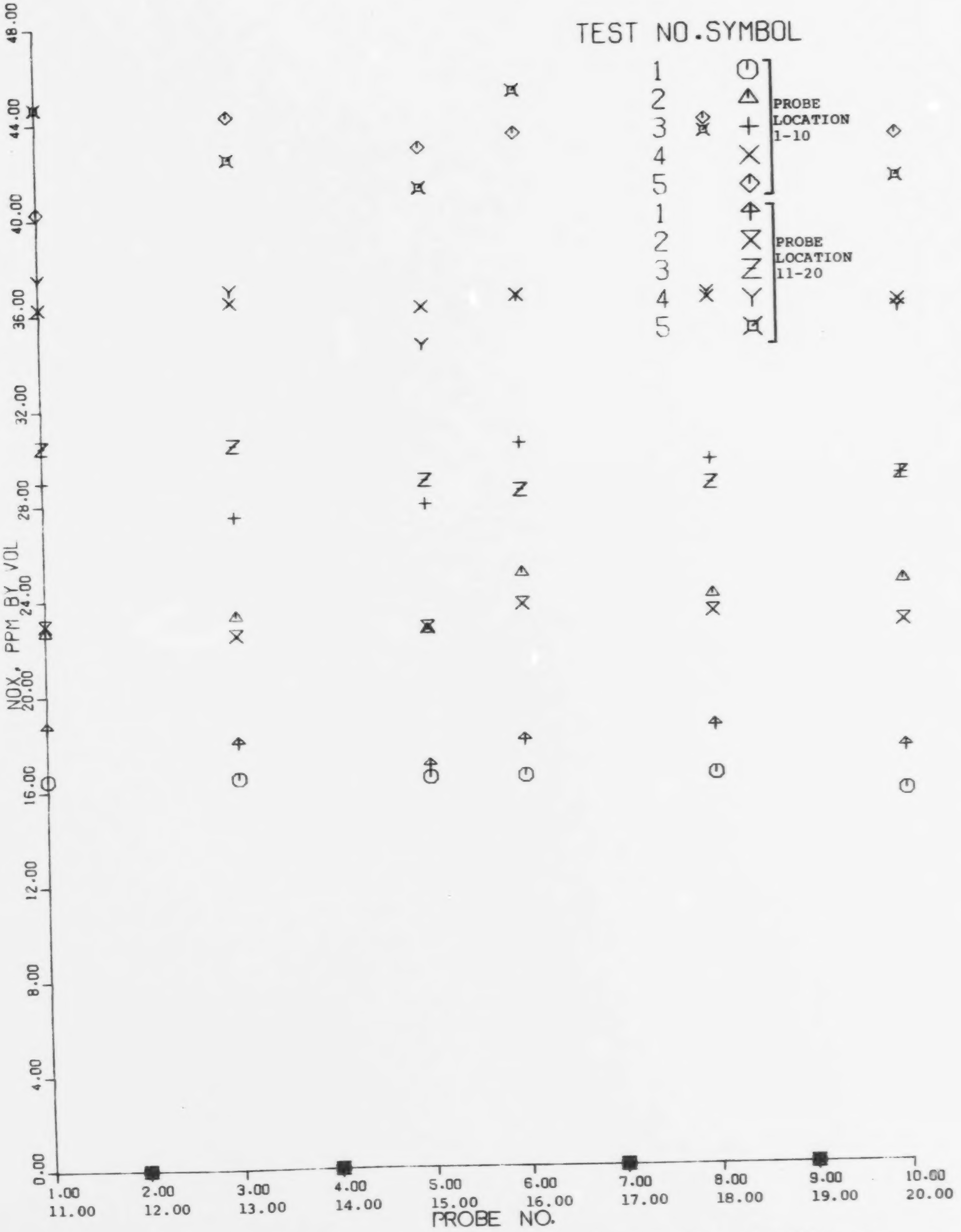

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GROUP 4

LARGE AUXILIARY POWER UNITS

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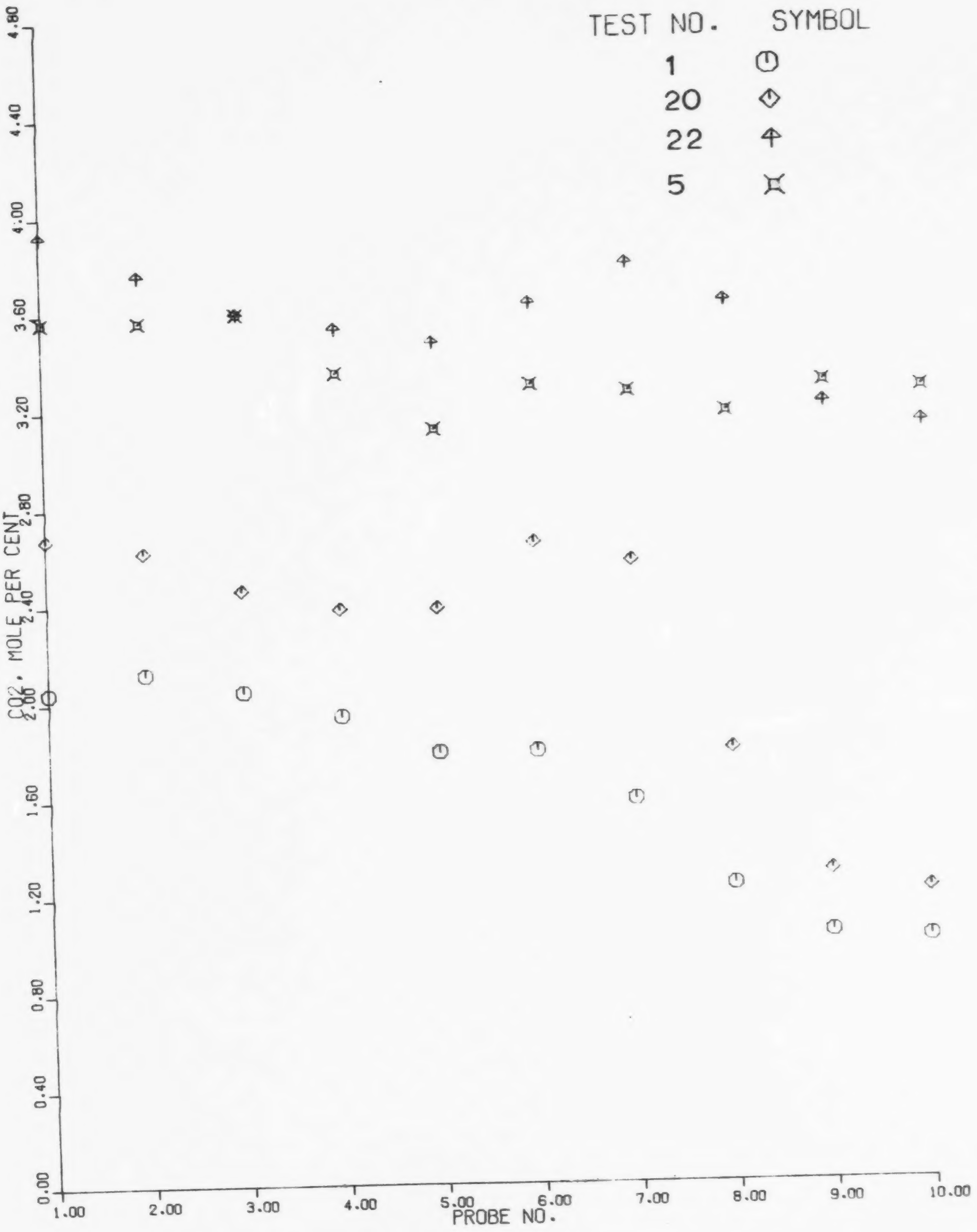

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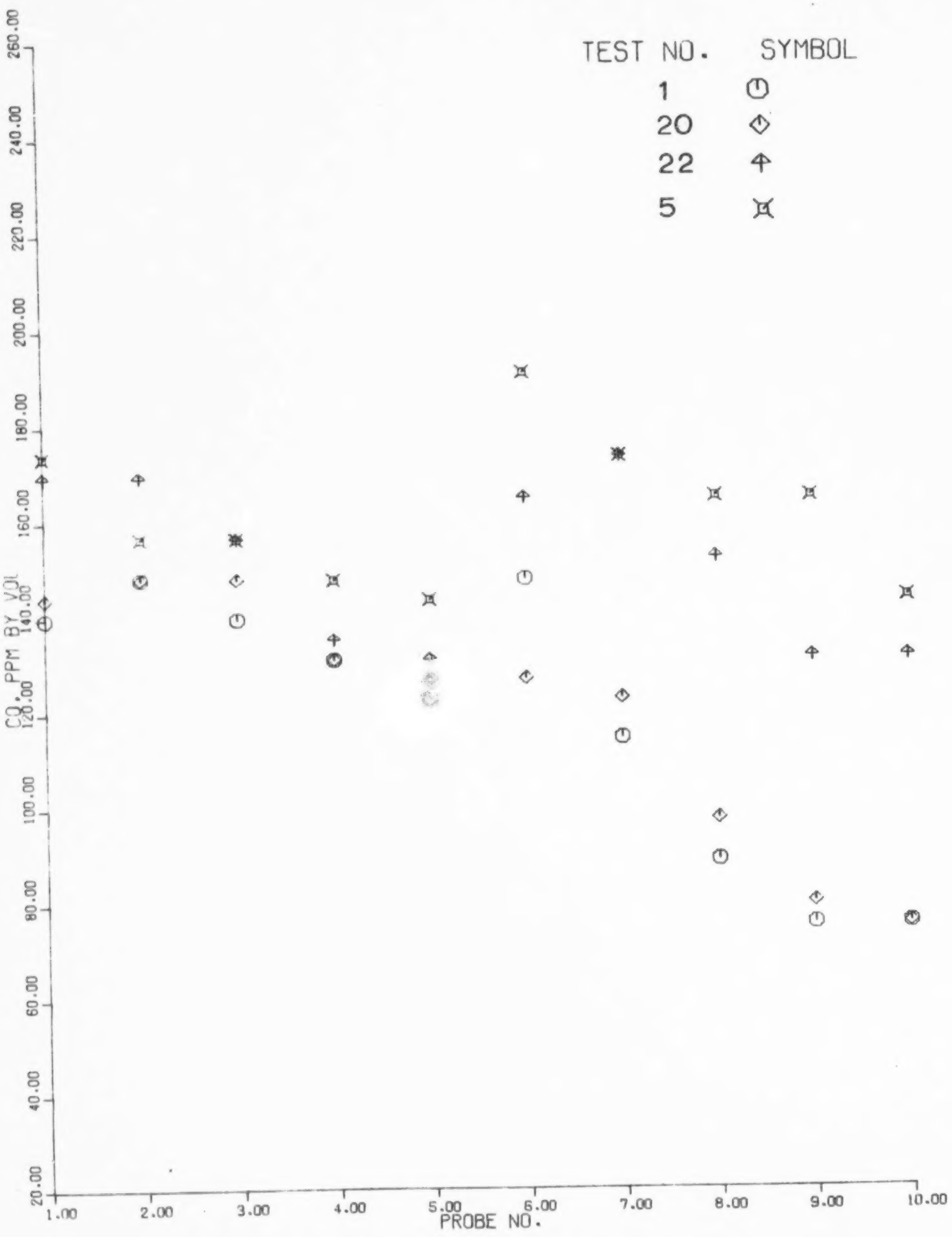

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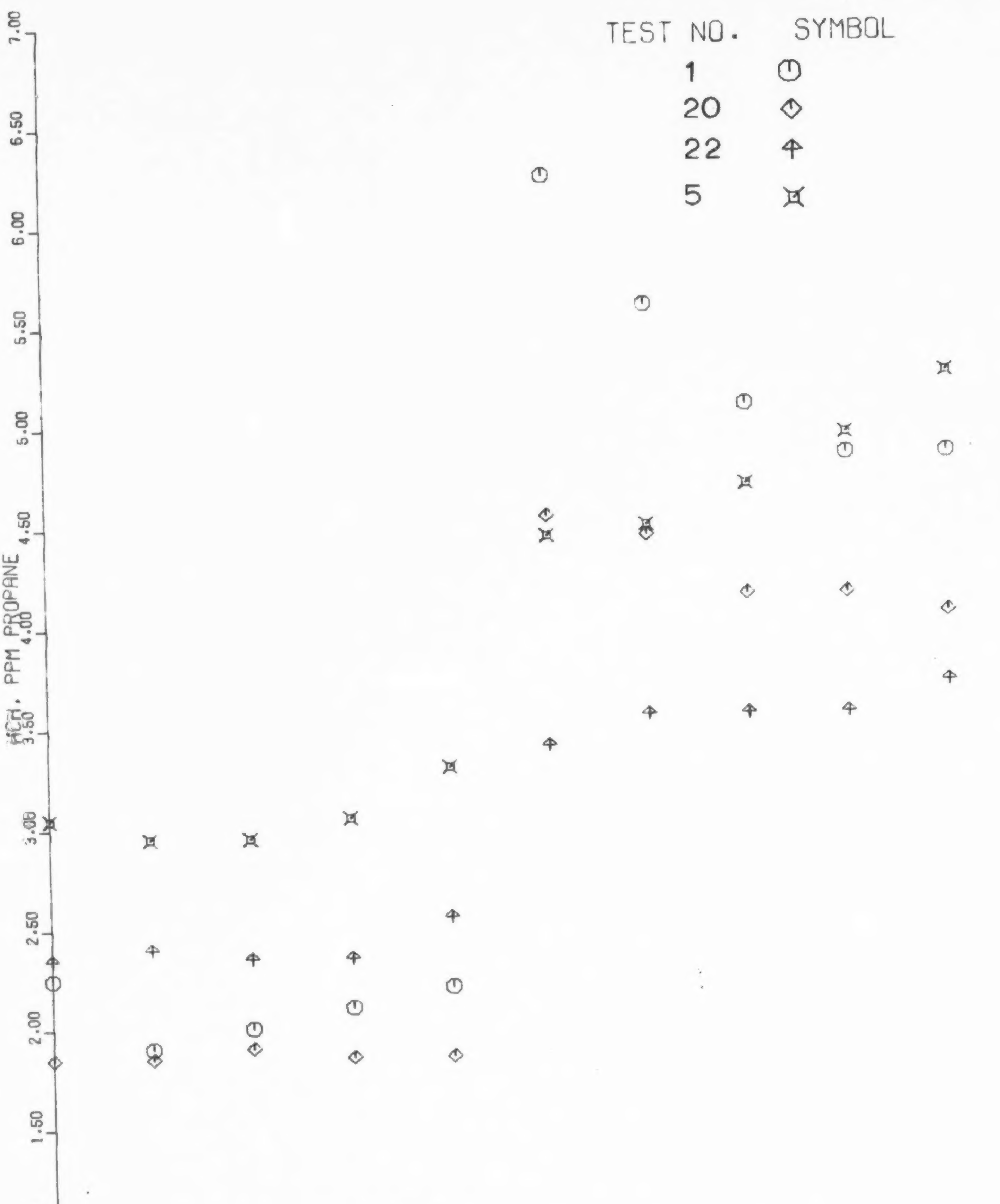

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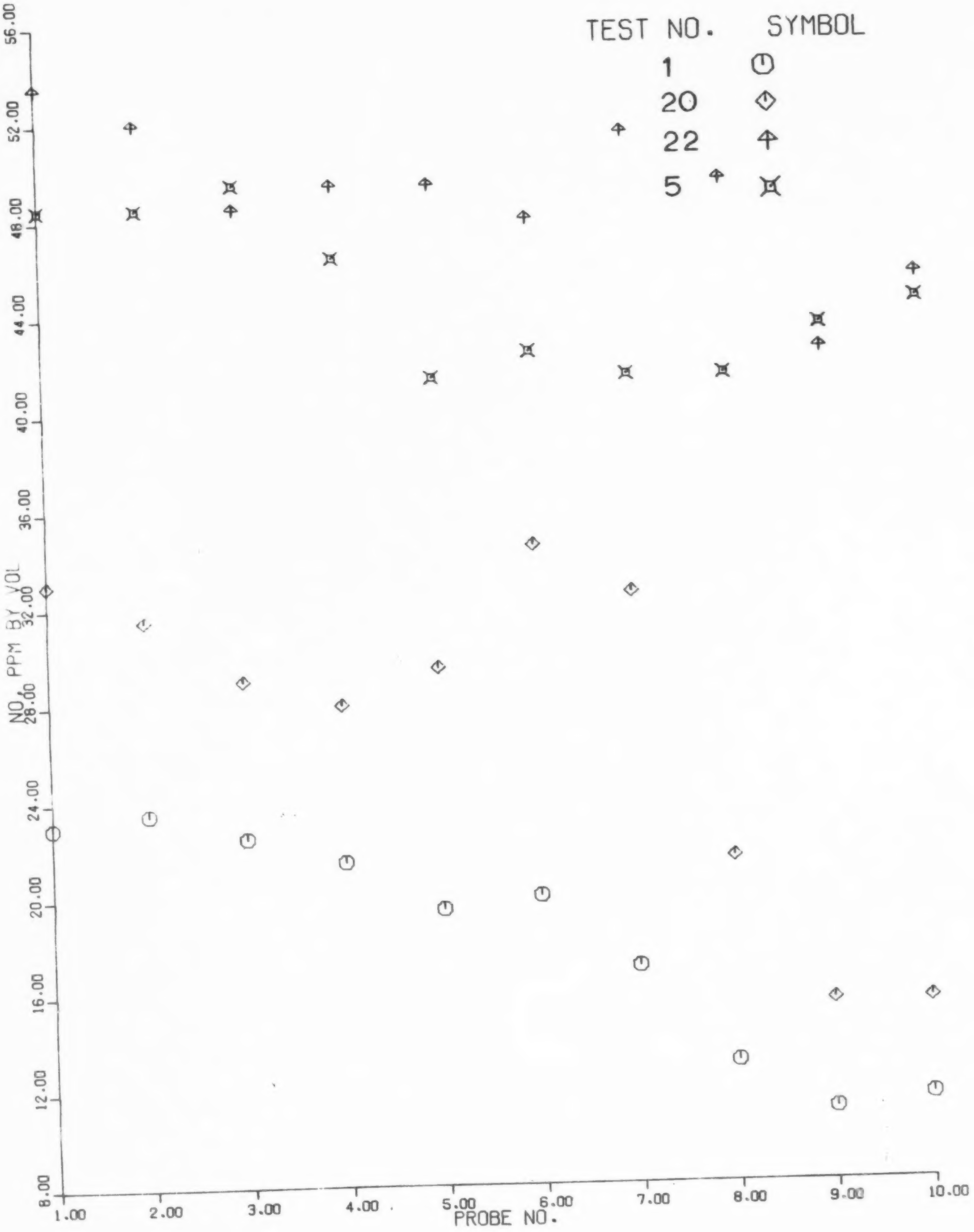

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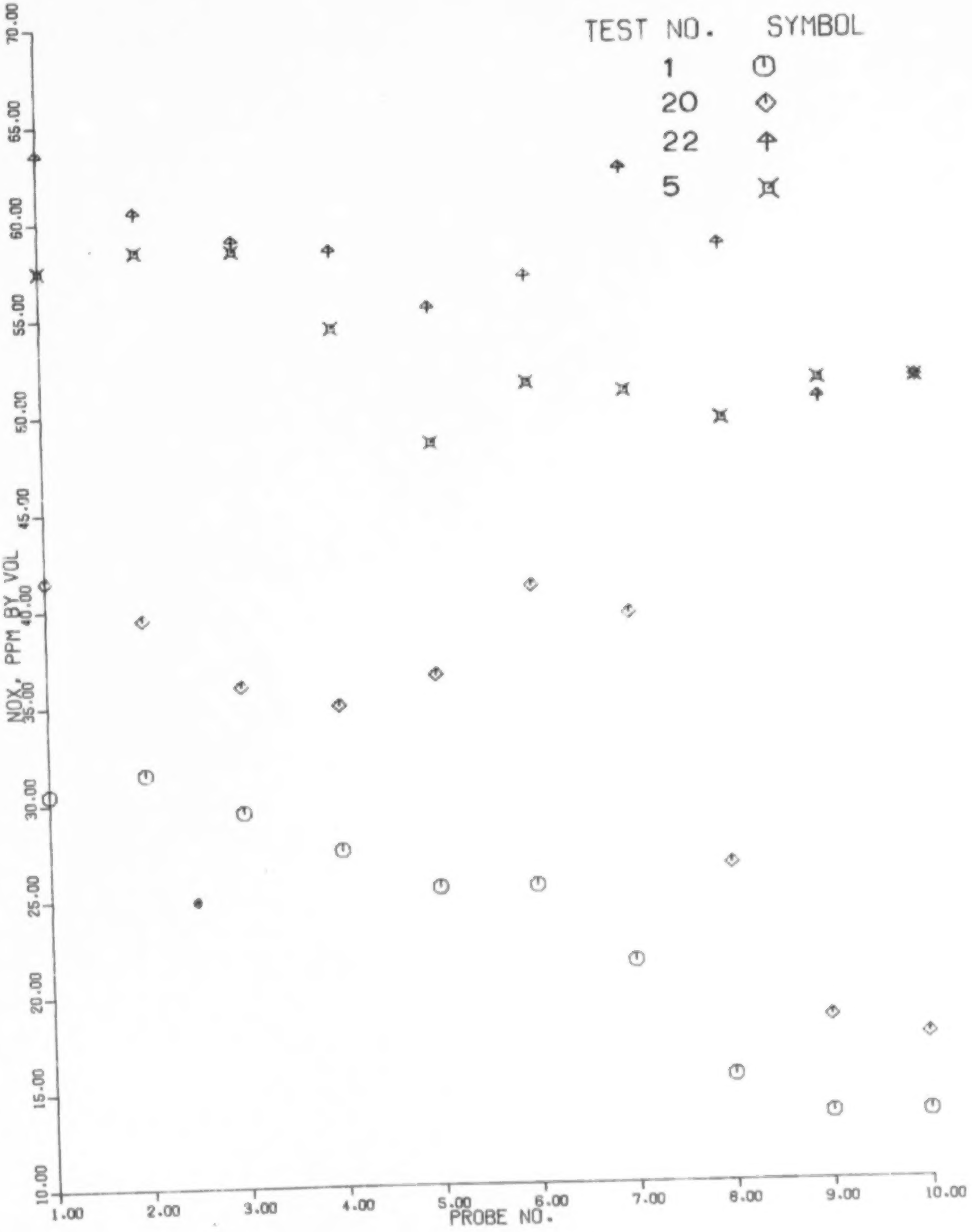

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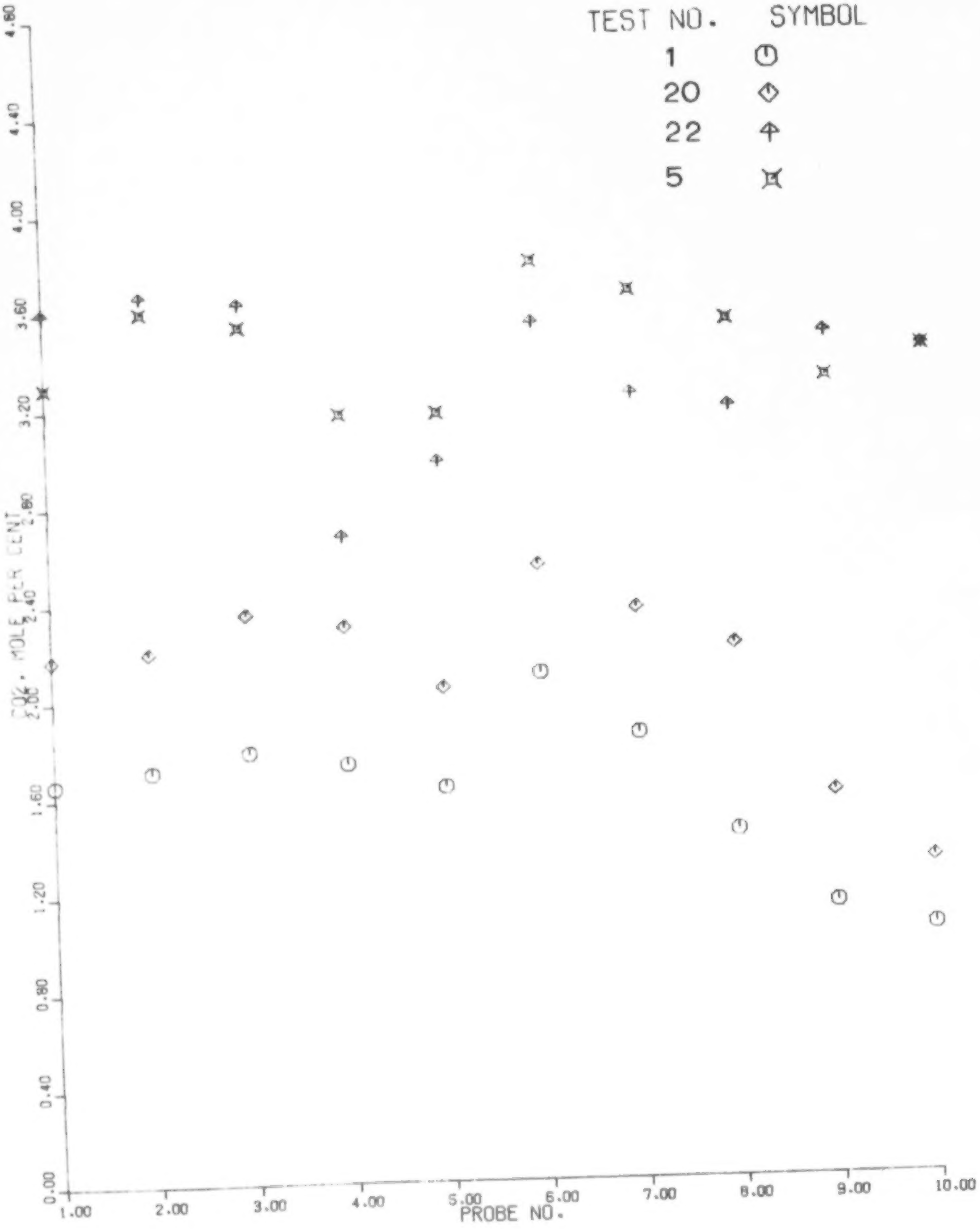

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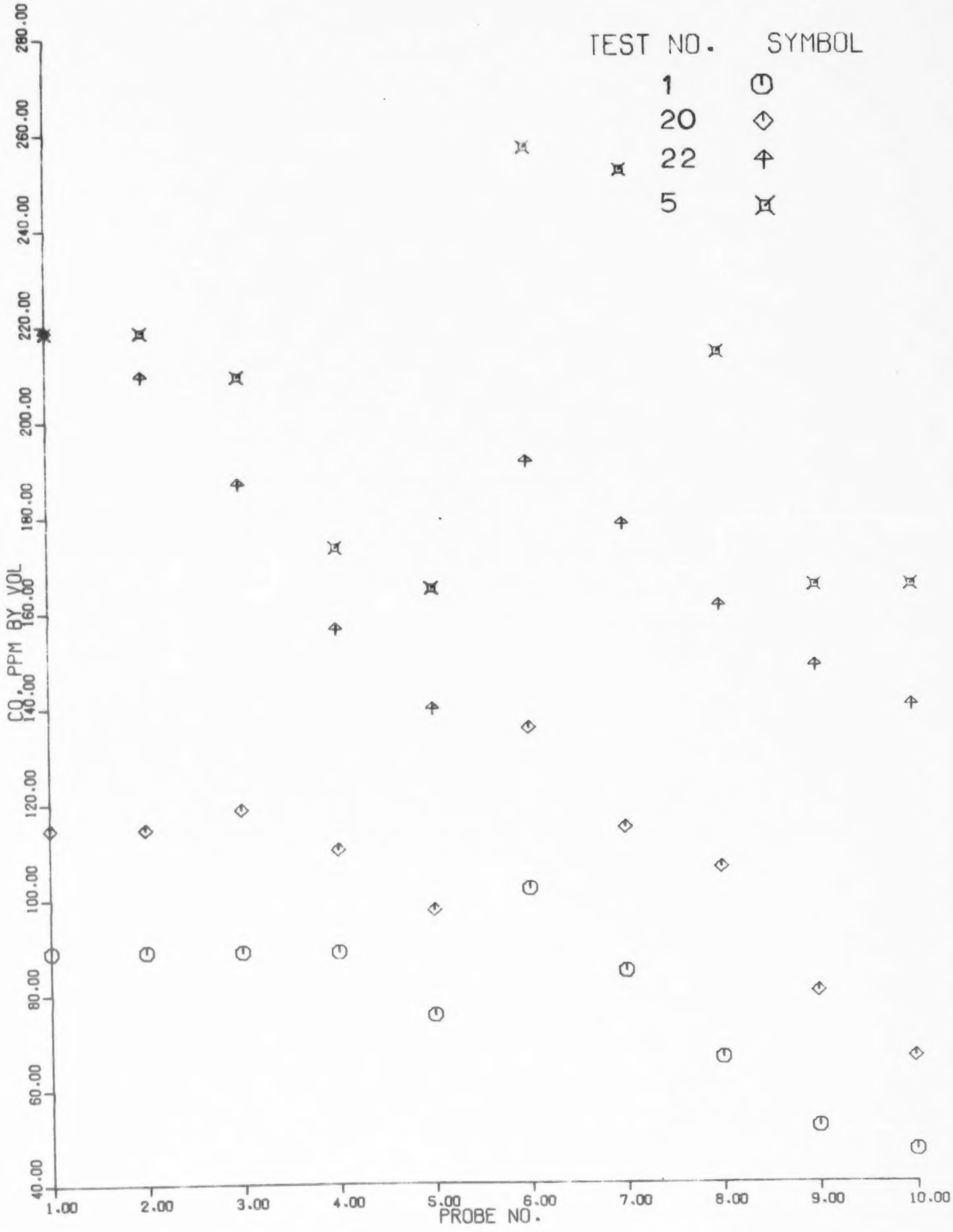

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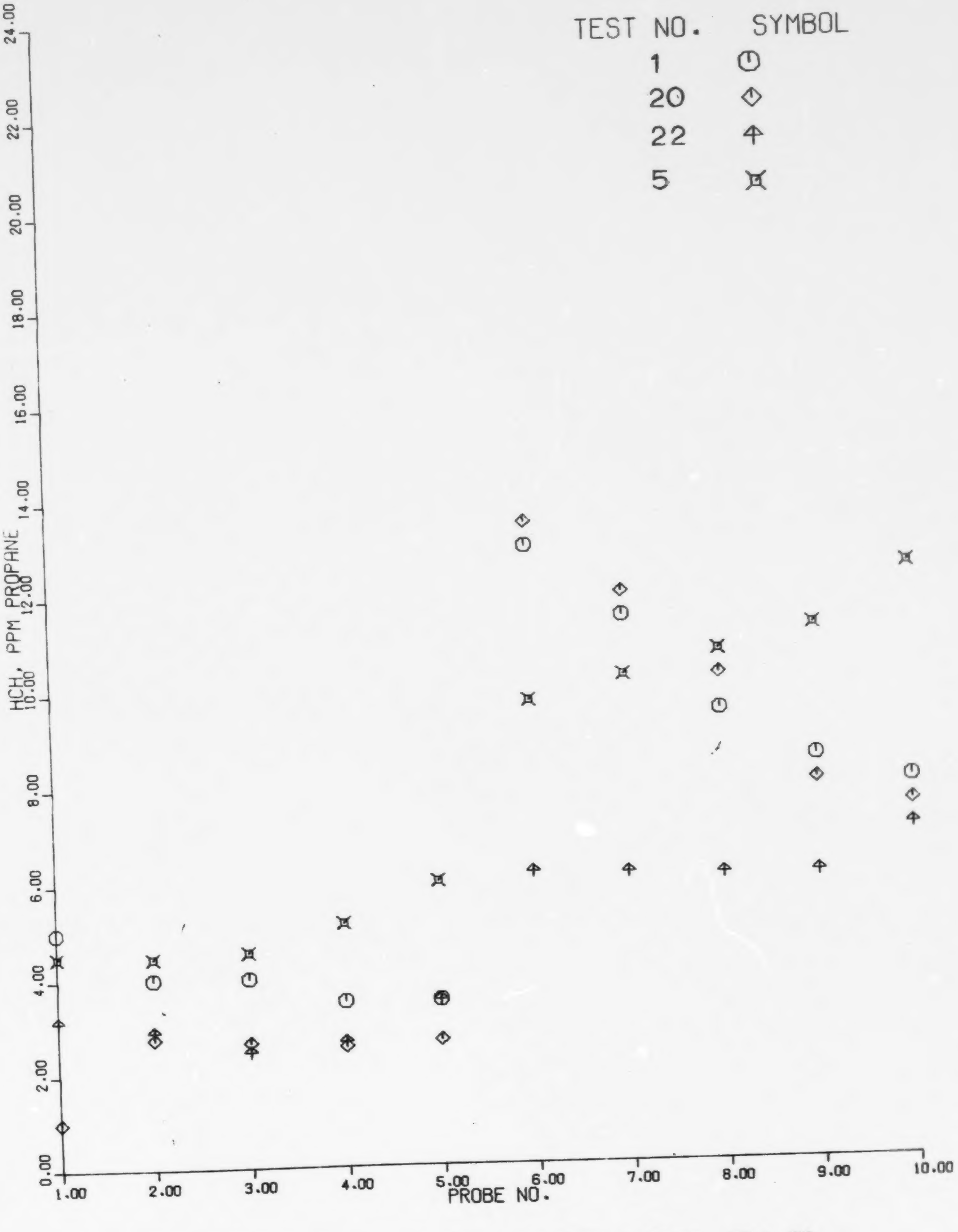

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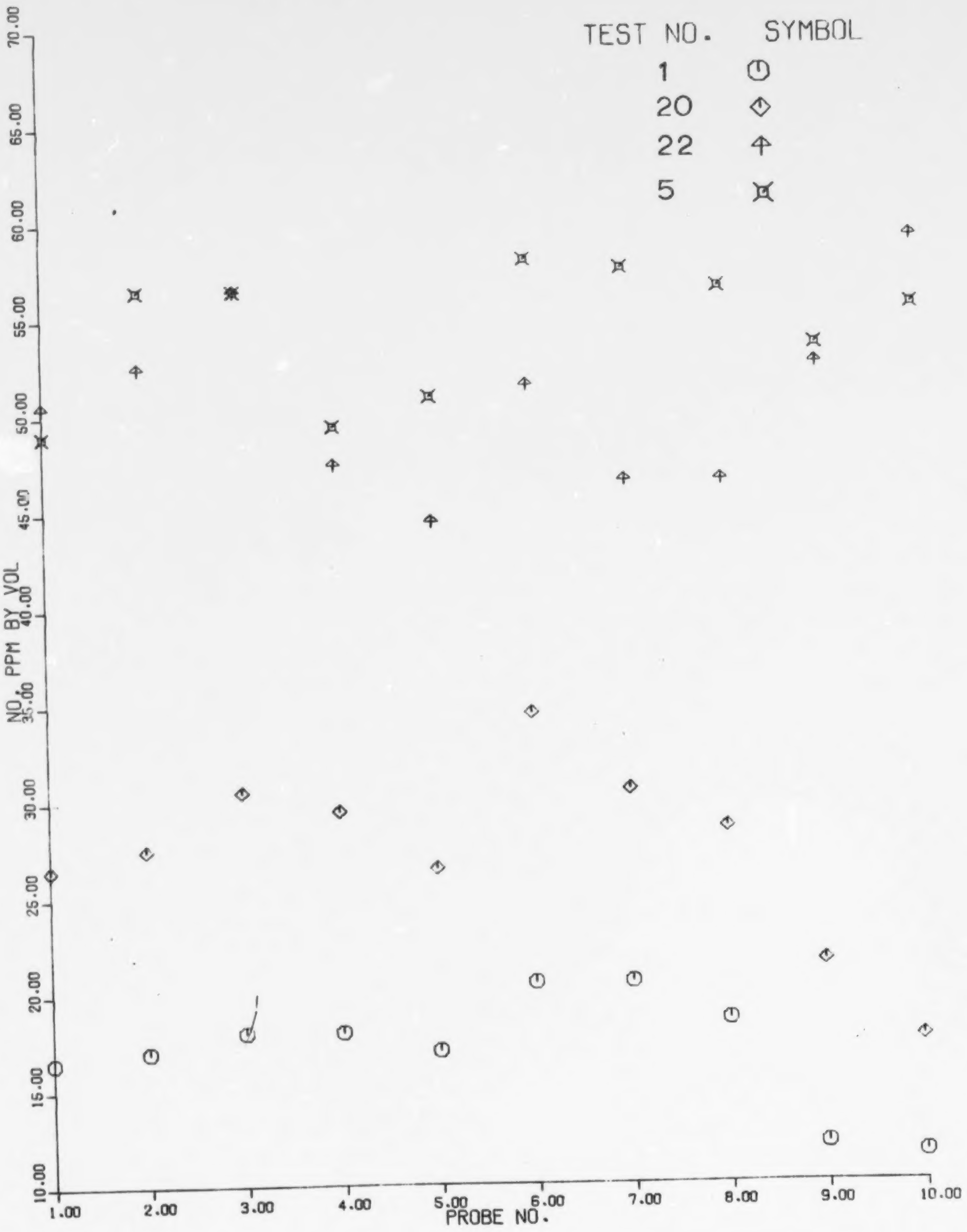

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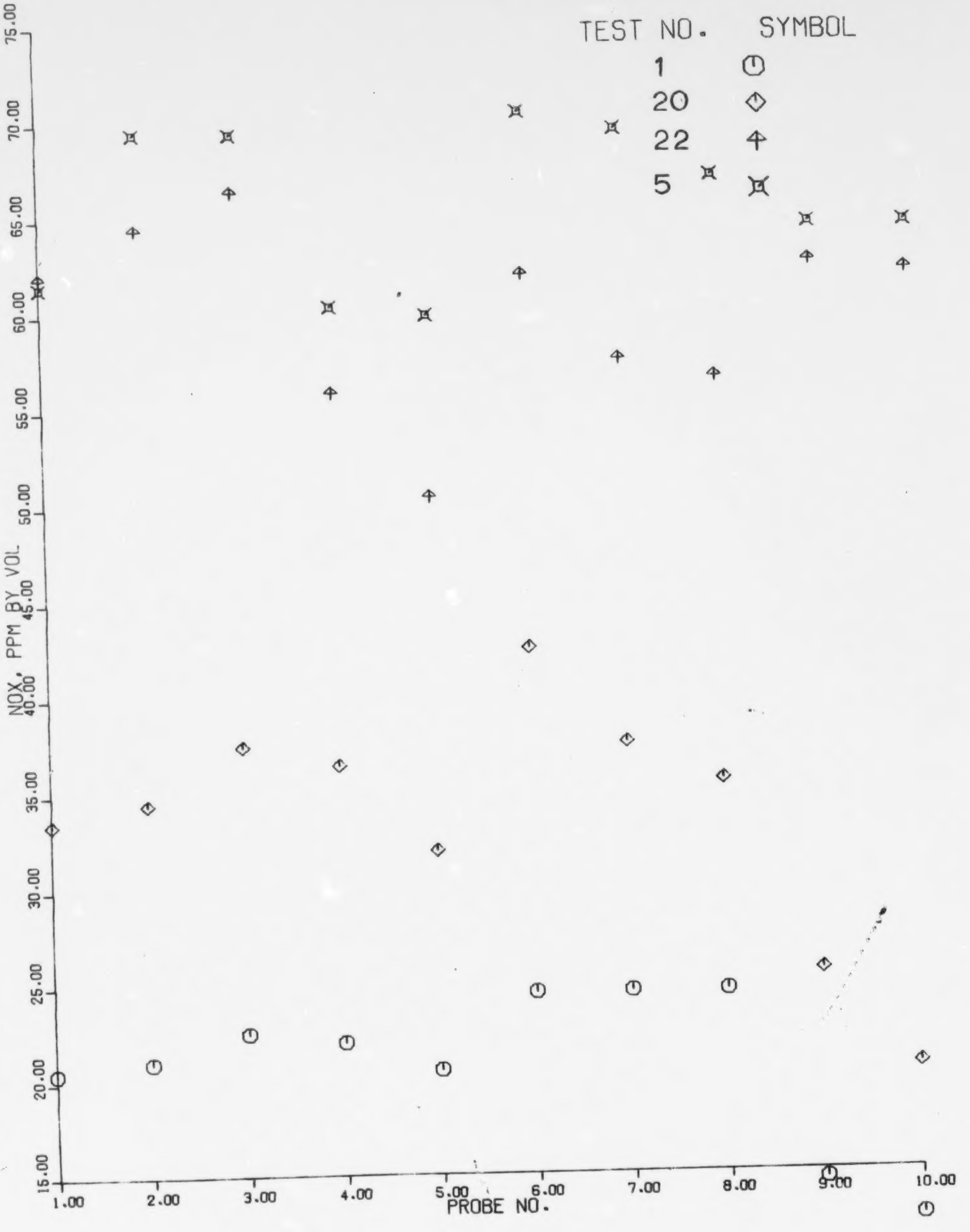

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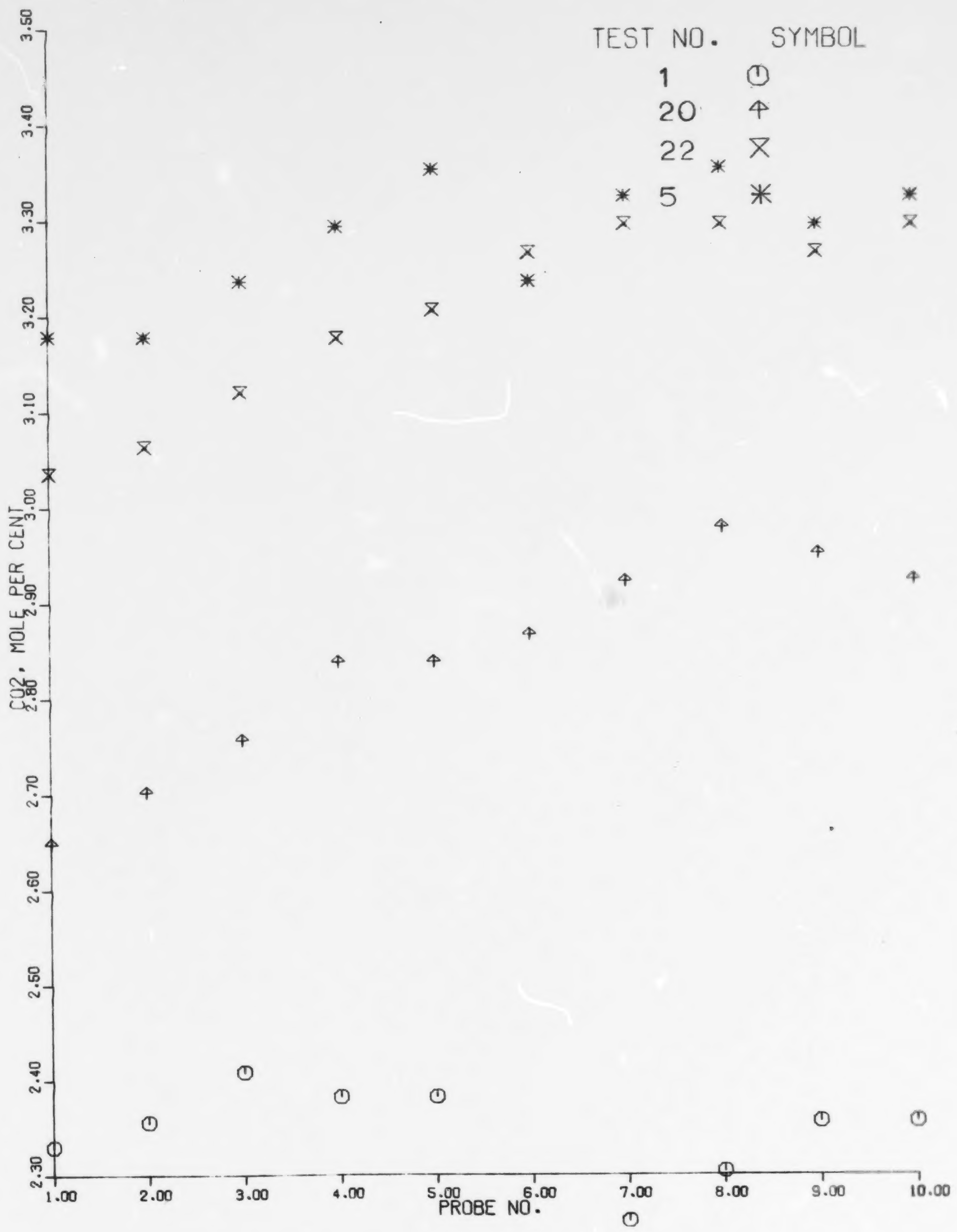

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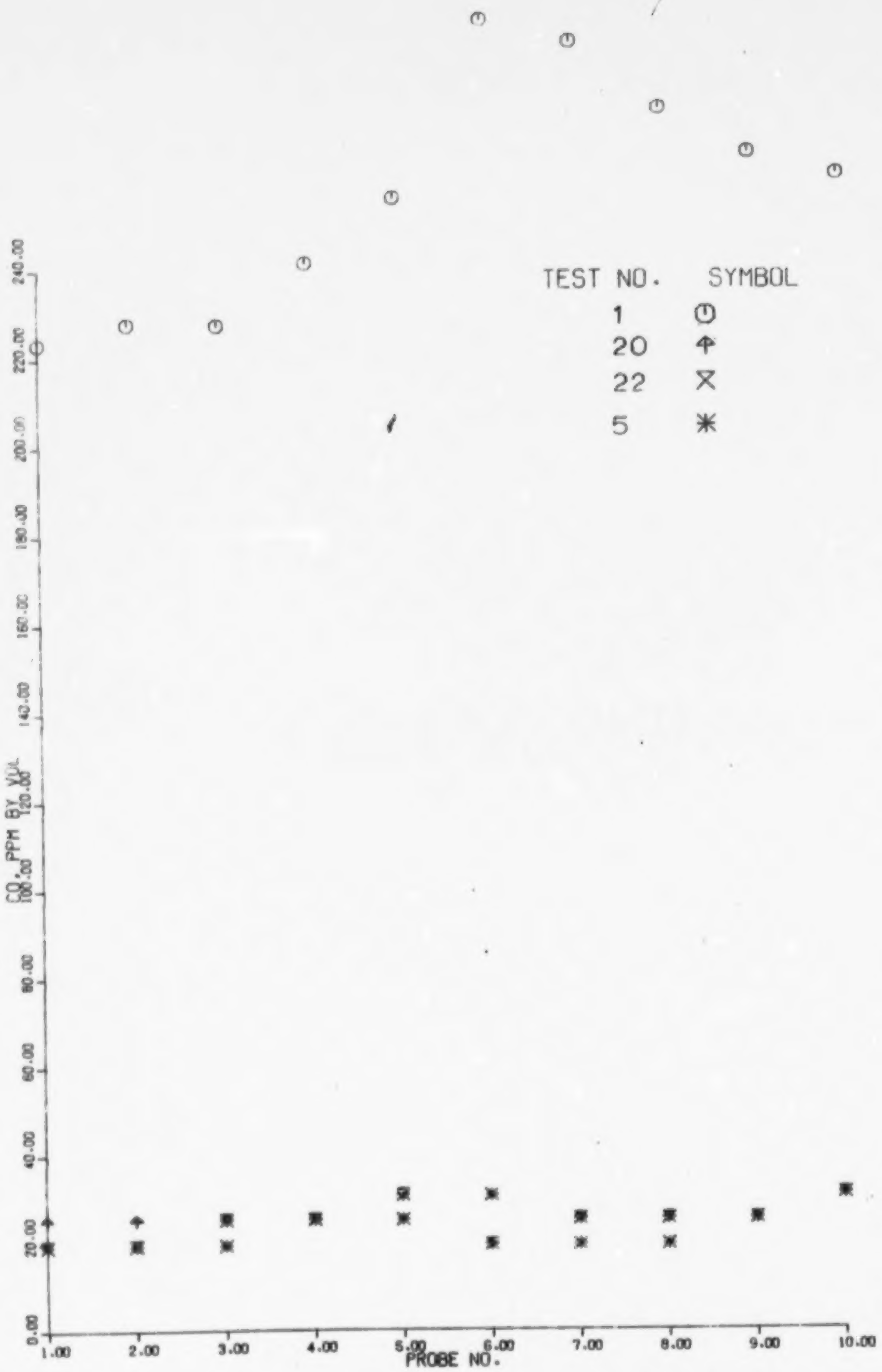

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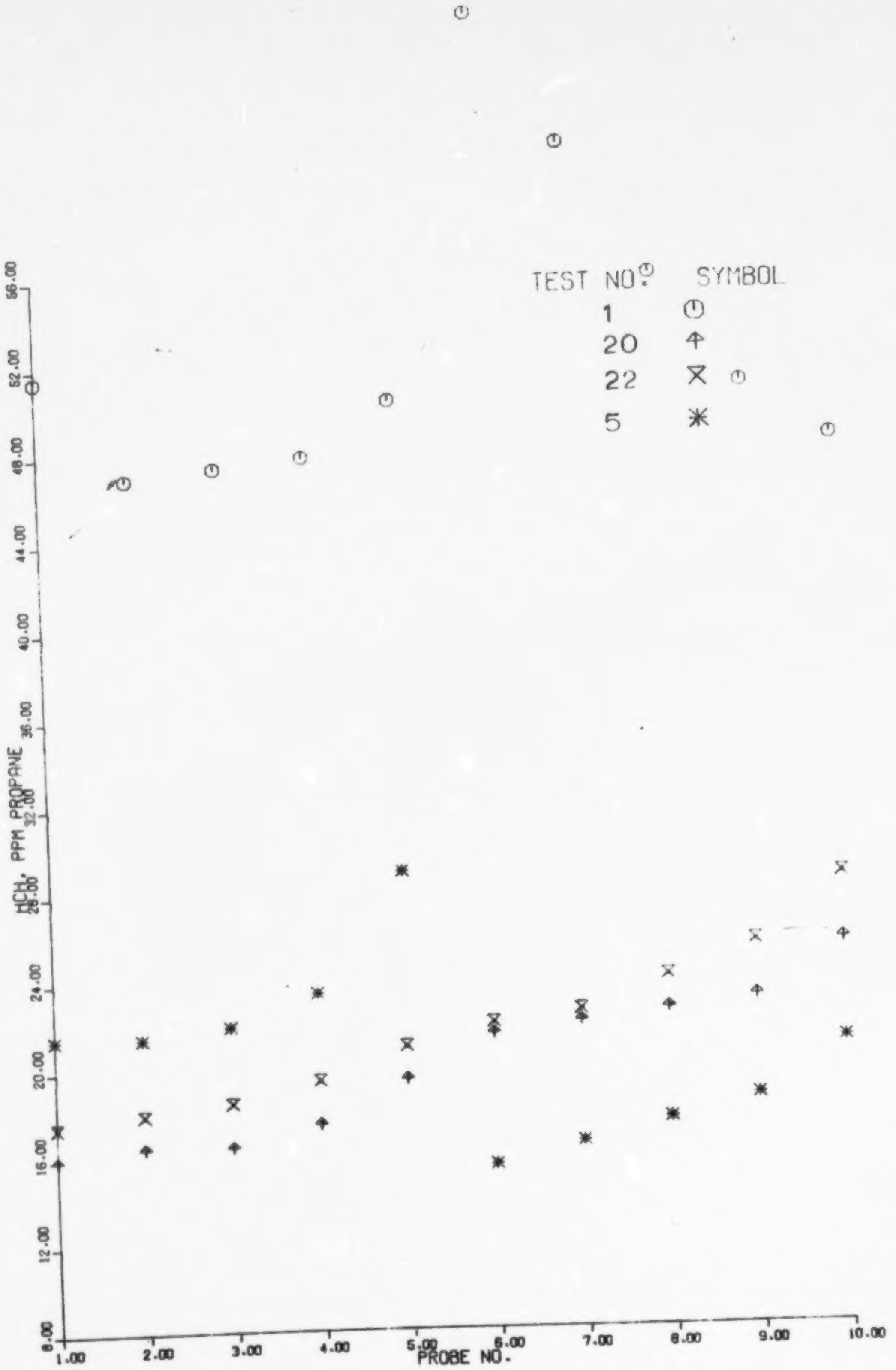

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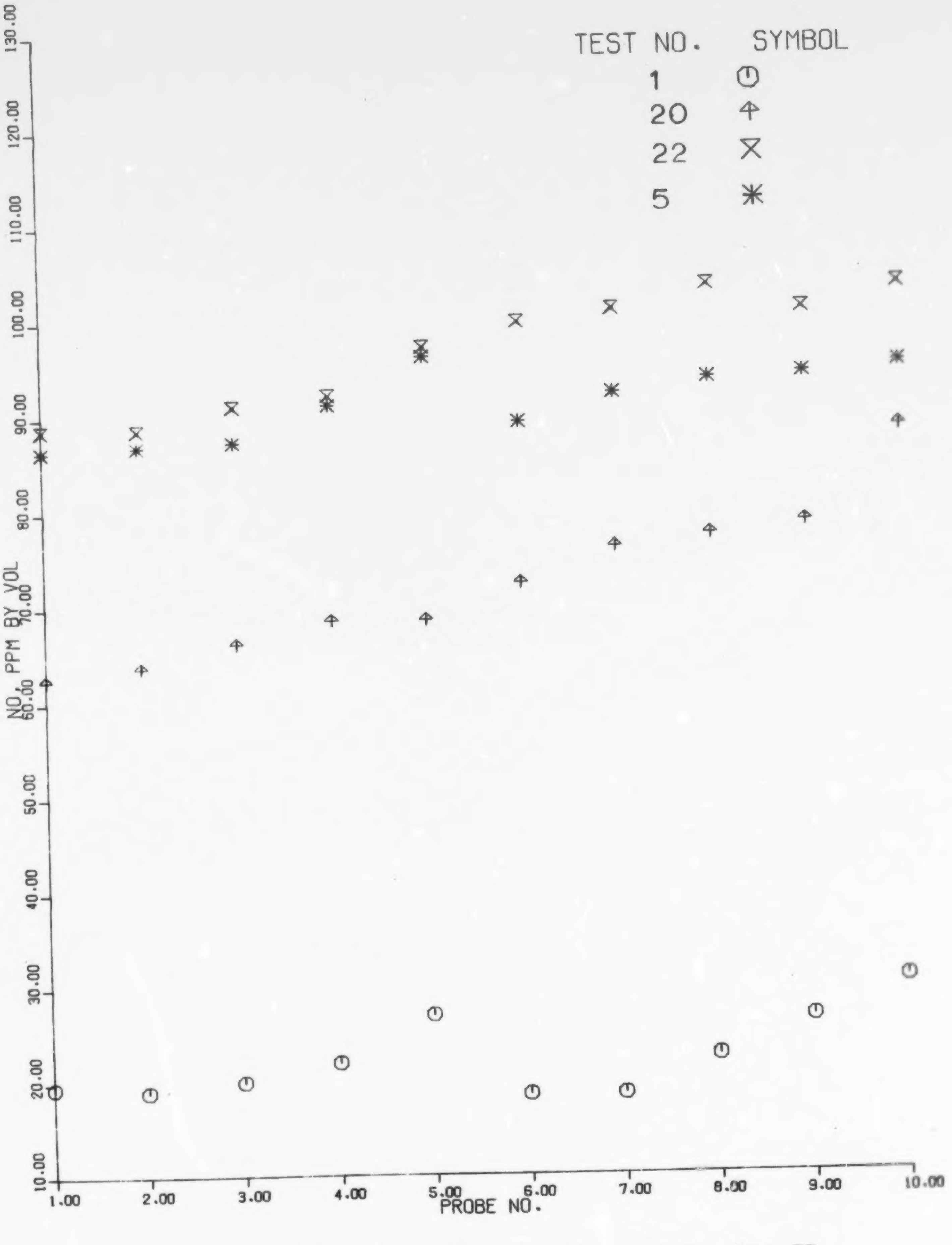

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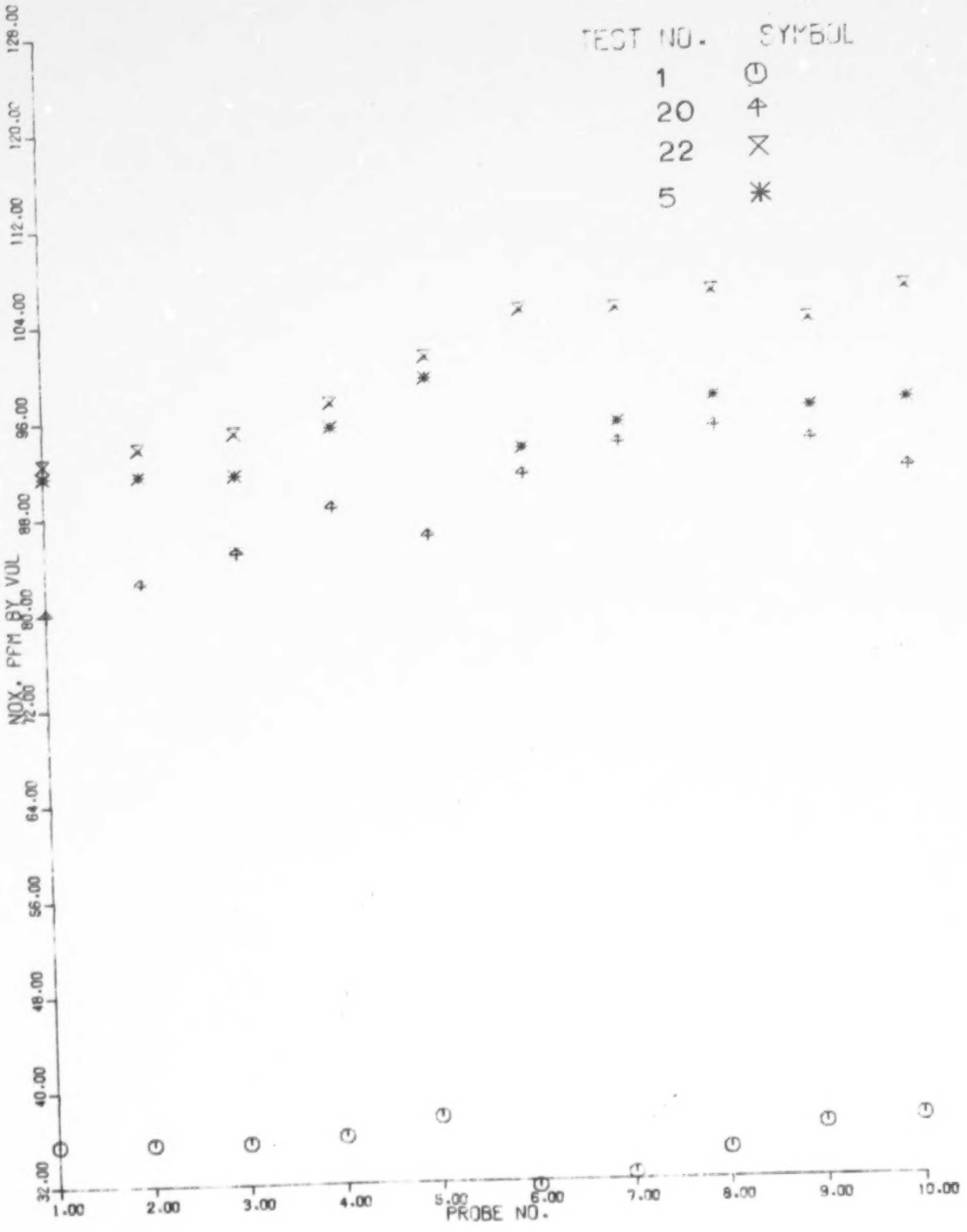

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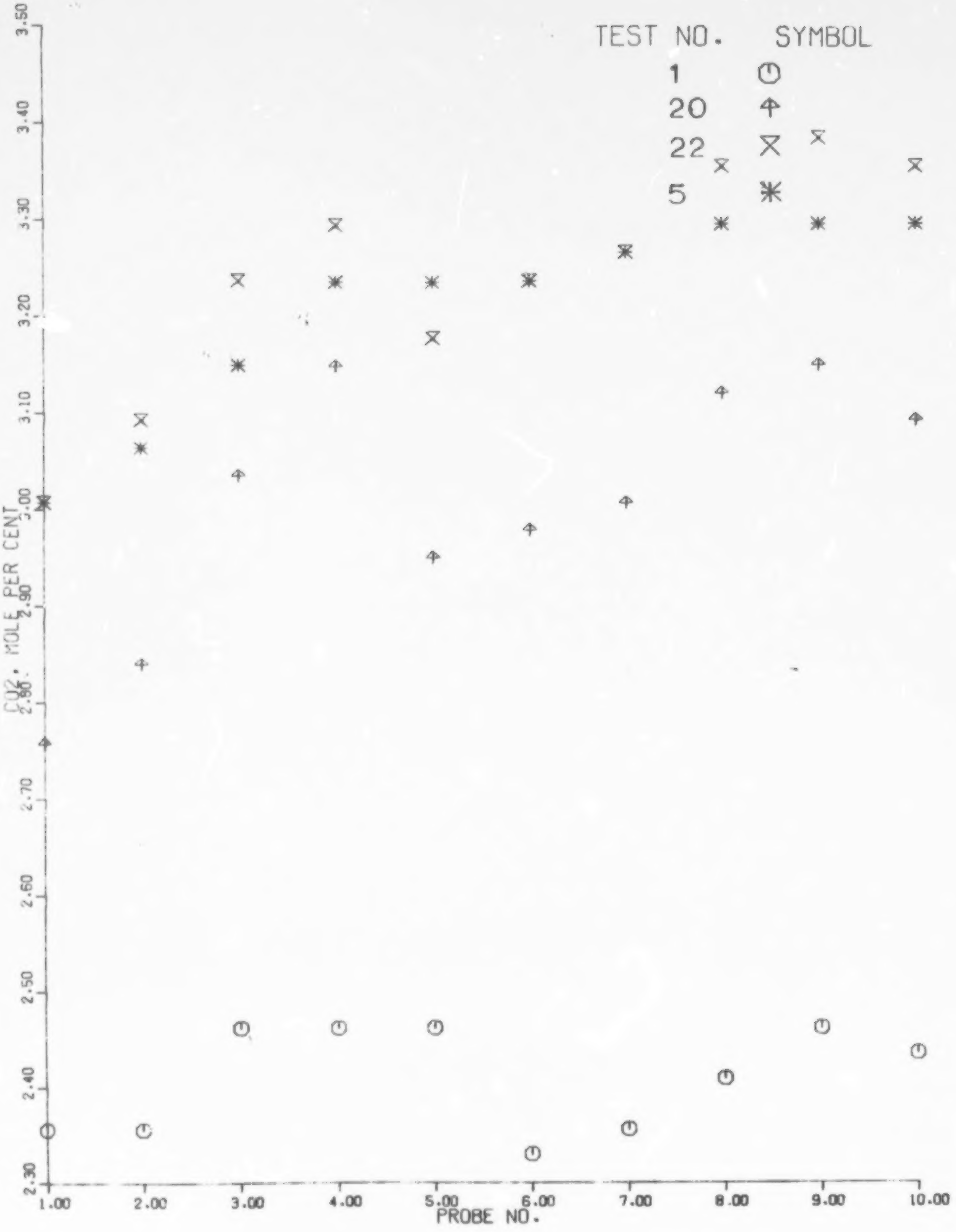

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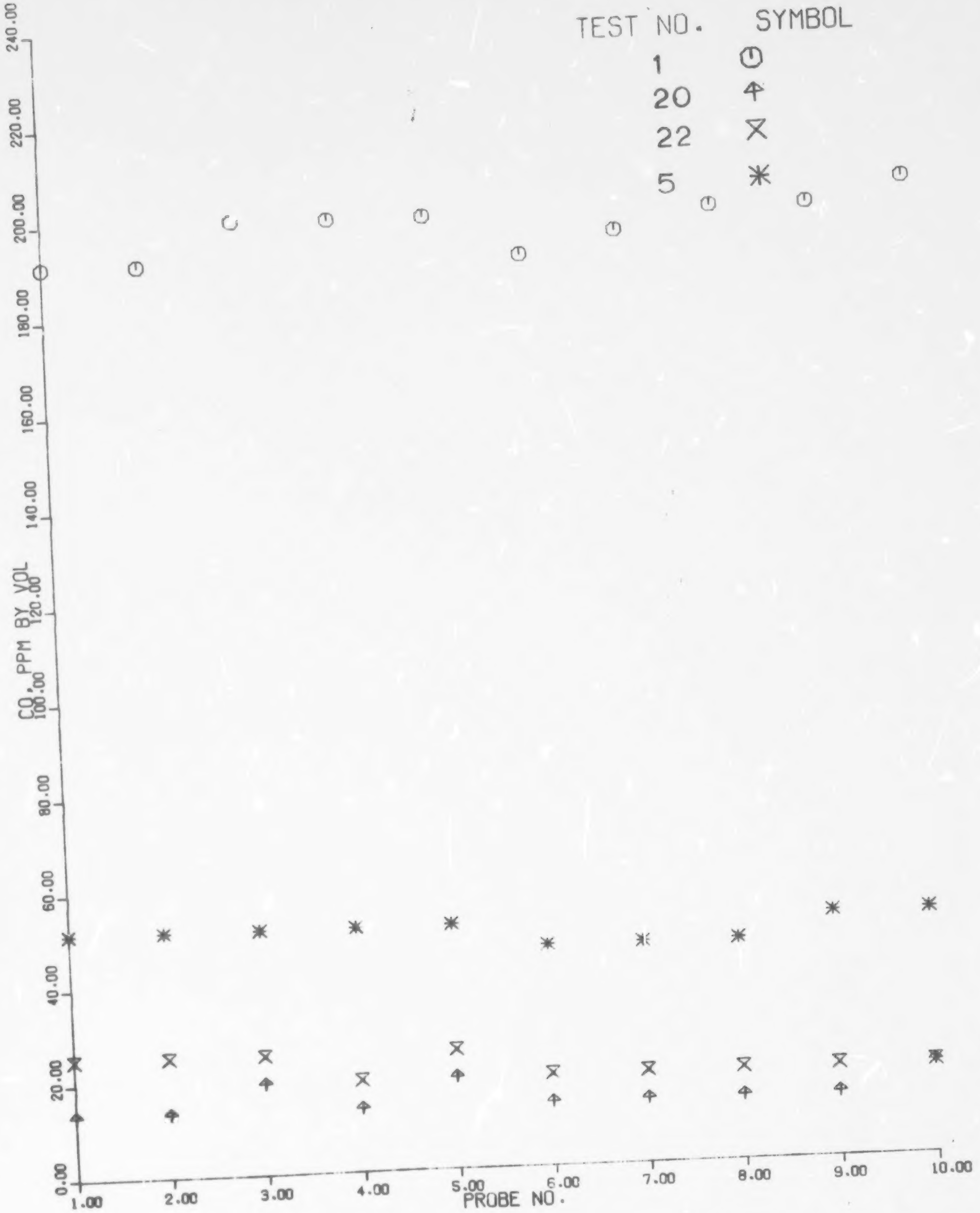

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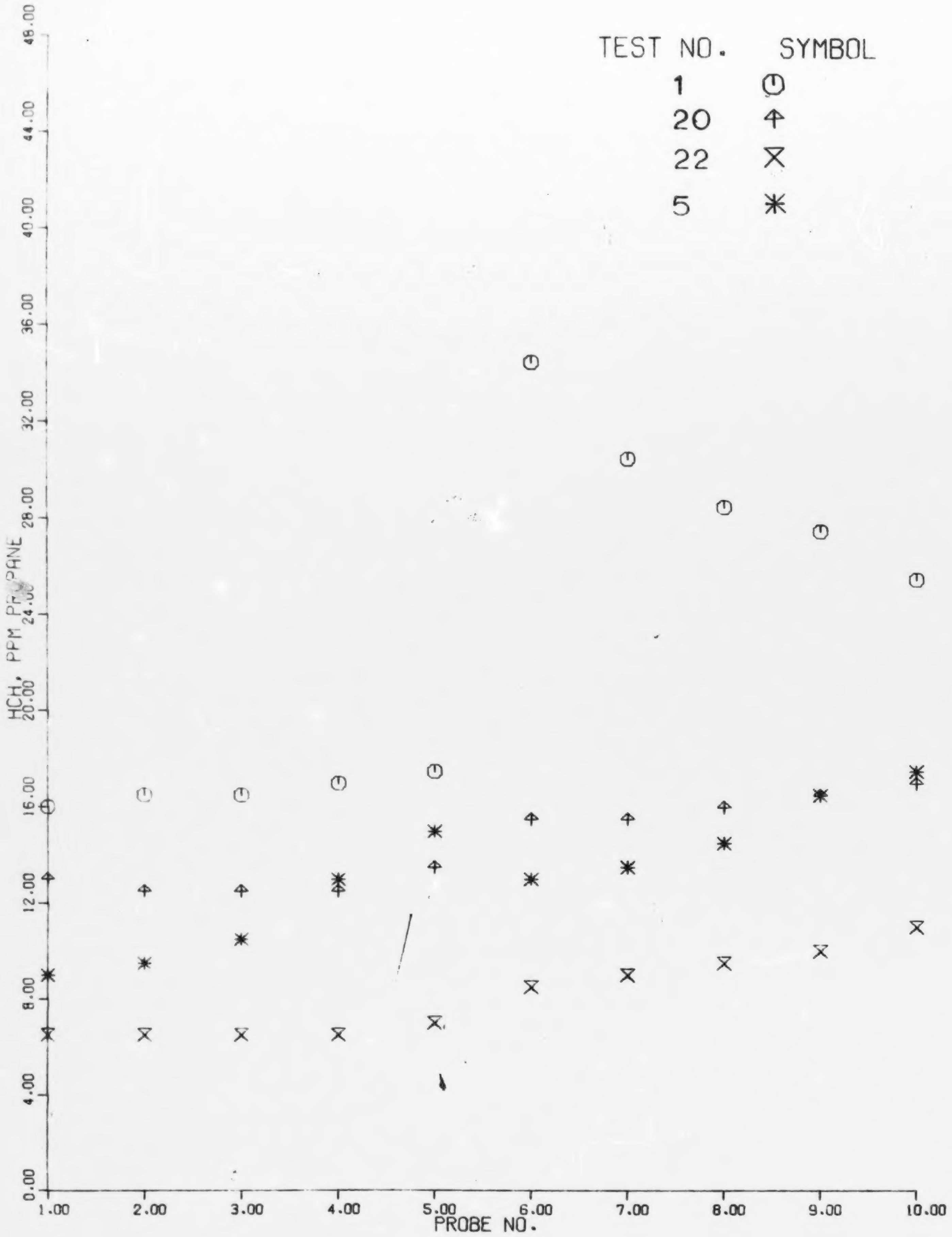

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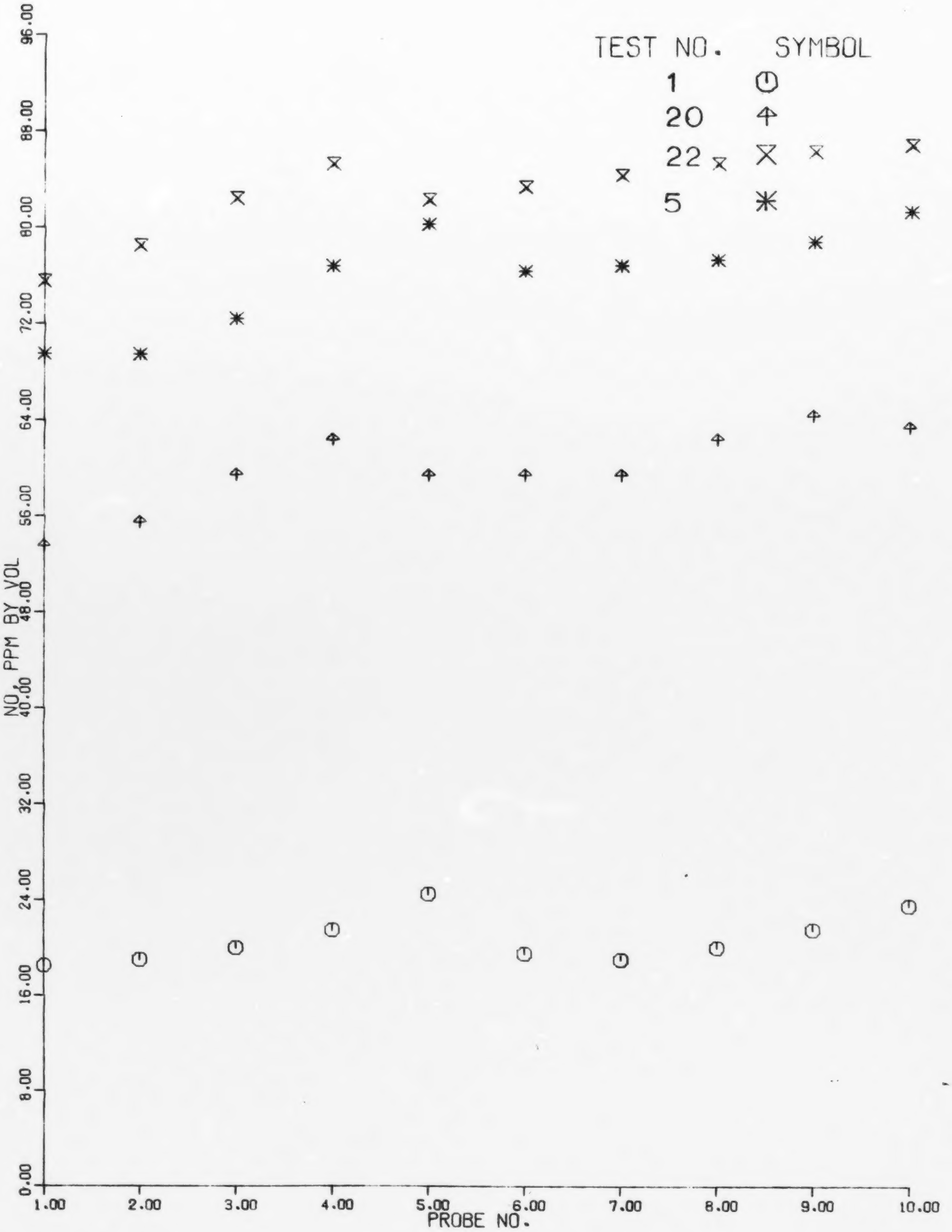

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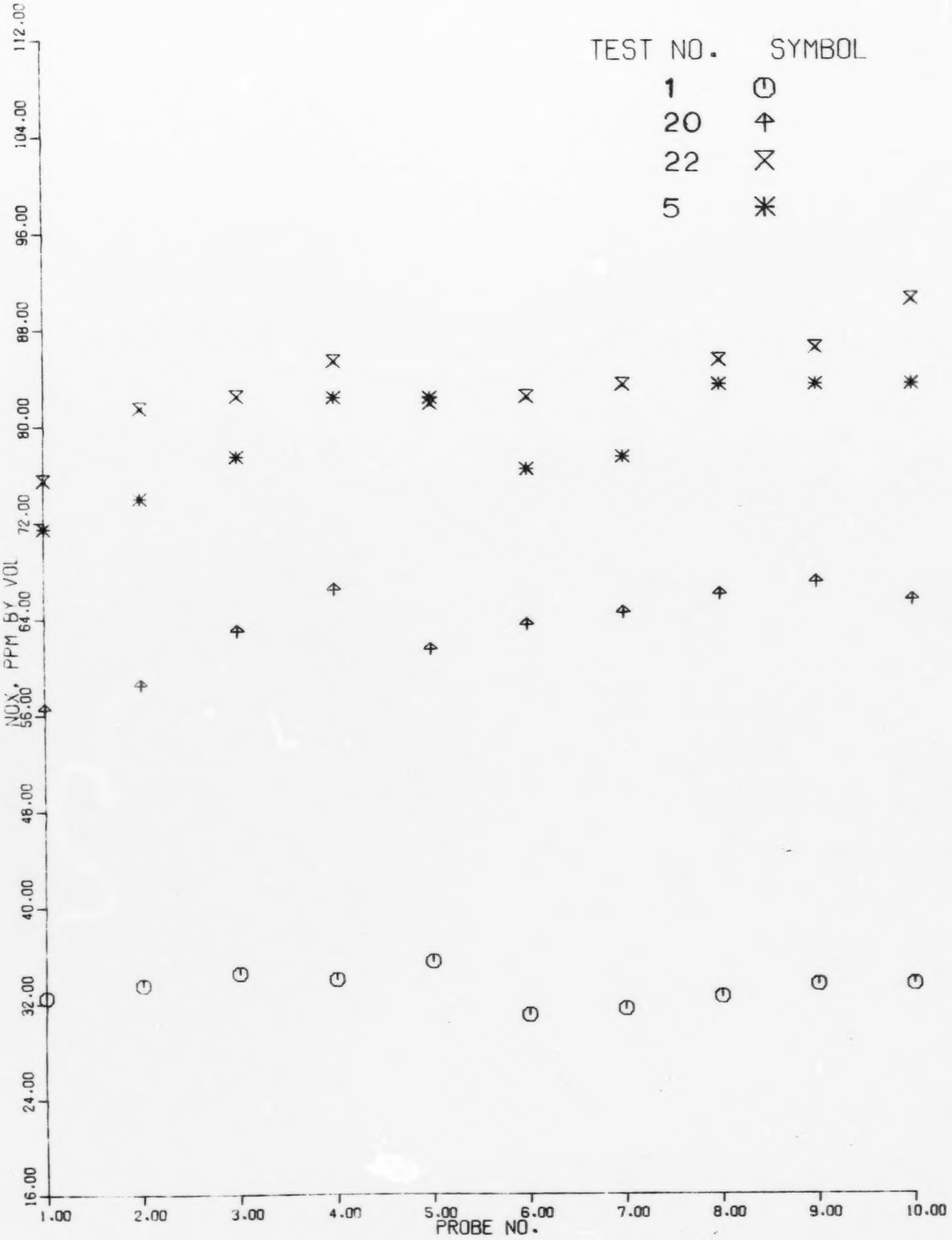

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APPENDIX E

FUEL ANALYSIS
TYPICAL GAS SAMPLING ANALYZER TRACES

PROPERTIES OF TEST FUELS USED IN OAP/EPA EXHAUST EMISSION STUDY

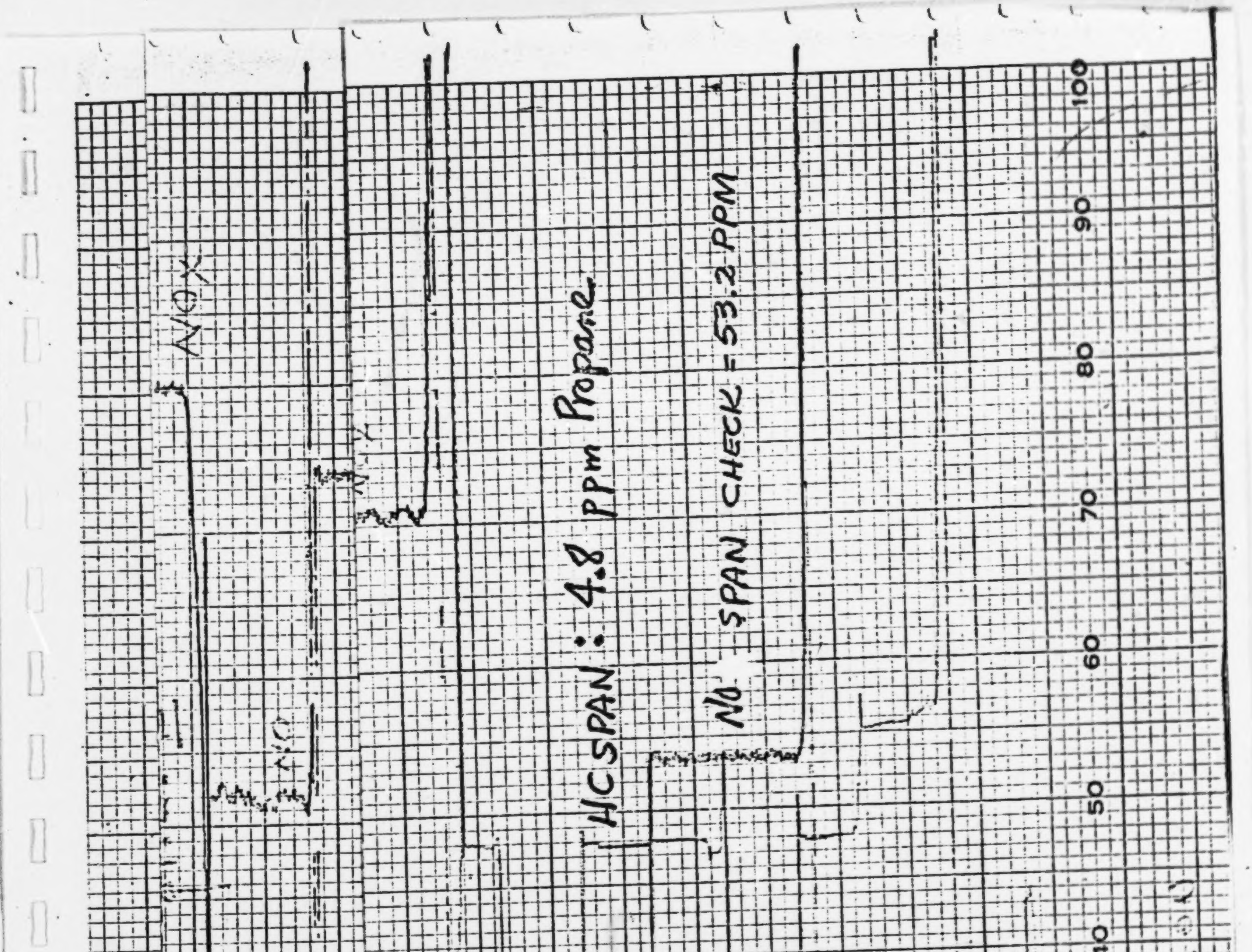
	Aviation Turbine Fuels			Diesel Fuel
Specification	MIL-T-5624G	MIL-T-5624G	ASTM D 1655-68	VV-F-800
Grade	JP-4	JP-5	Jet A	DF-2
Fuel Type	Wide Cut	Kerosene	Kerosene	Regular Diesel
Gravity, °API (Sp. Gr.)	49.9 (0.780)	39.8 (0.826)	43.1 (0.810)	34.6 (0.852)
Distillation, °F				
Initial Boiling Point	180	352	324	396
5 Percent Evaporated	228	372	352	431
10 Percent Evaporated	240	380	362	445
20 Percent Evaporated	260	385	377	464
30 Percent Evaporated	276	398	388	482
40 Percent Evaporated	292	404	398	498
50 Percent Evaporated	312	410	408	514
60 Percent Evaporated	328	418	419	532
70 Percent Evaporated	340	426	431	552
80 Percent Evaporated	366	437	446	572
90 Percent Evaporated	392	454	466	605
95 Percent Evaporated	413	469	484	---
Final Boiling Point	448	486	499	651
Distillation Loss, Percent	98.5	98	98	94
Flash Point, °F	---	160	156 (2)	196
Reid Vapor Pressure, psi	1.20 (1)	---	---	---
Viscosity at 100°F, cSt	---	1.59	1.49	2.94
at -30°F, cSt	---	12	10	49
Aromatics, Vol Percent	7	16	15	29
Olefins, Vol Percent	1	2	1	2
Smoke Point, mm	26	22	24 (3)	16
Smoke Volatility Index	64.6	---	---	---
Heat of Combustion, Net Btu/lb	18,520	18,430	18,470	18,280
Hydrogen - Carbon Weight Ratio	0.1671	0.1576	0.1618	0.1507

Notes:

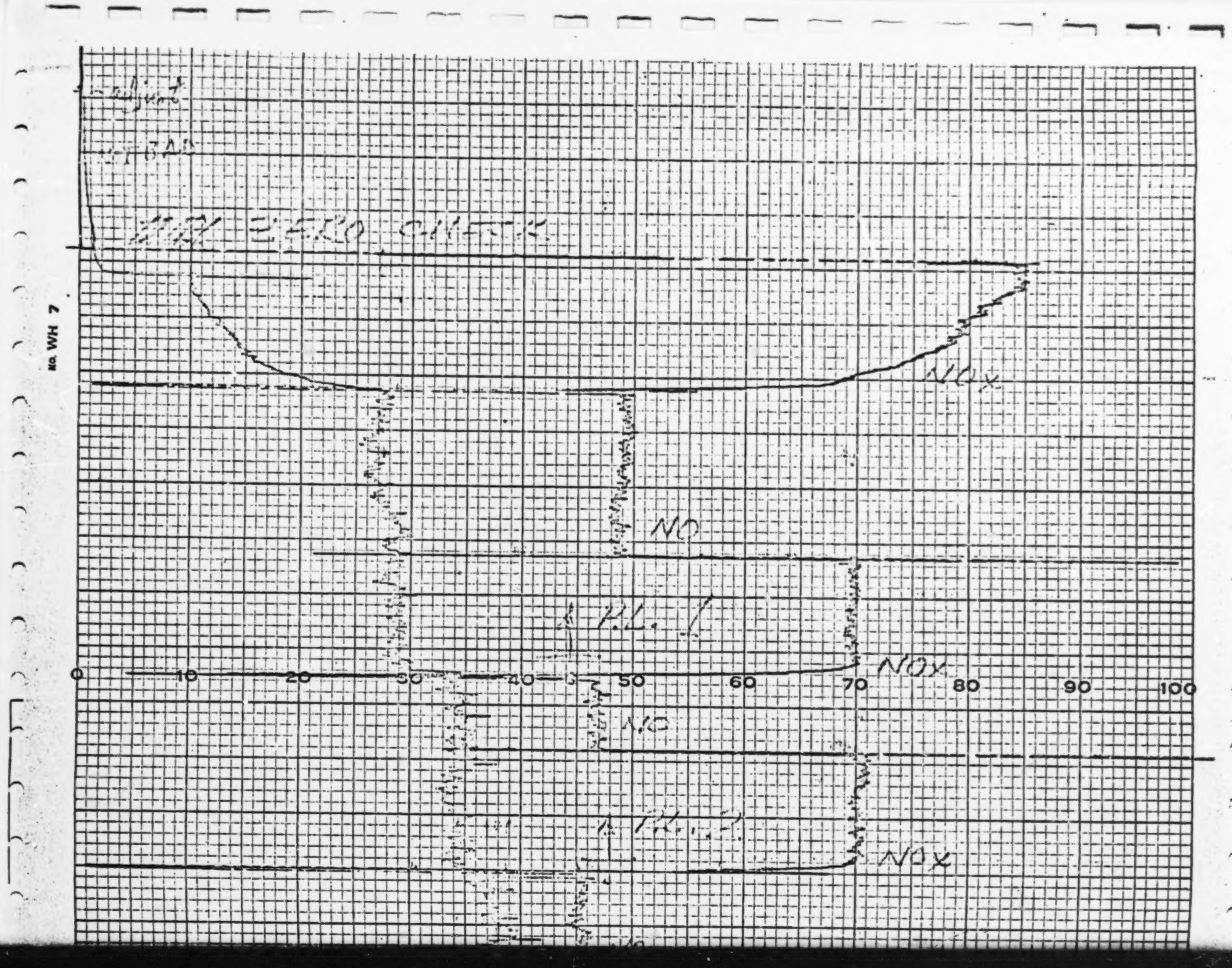
(1) Reid Vapor Pressure of JP-4 does not meet MIL-T-5624G specification of 2.0-3.0 psi.

(2) Flash Point of Jet A does not meet ASTM D 1655-68 specification of 110-150°F.

(3) Smoke Point of Jet A doesnot meet ASTM D 1655-68 specification of 25 min minimum.



L RECORDER TRACE
/ T-76 ENGINES
OCARBON / NO-NO_x DATA


adjust
span
AIR ZERO CHECK
NOx
NO
P.L. 1
NOx
NO
P.L. 2
NOx
0
10
20
30
40
50
60
70
80
90
100
NO. WH 7

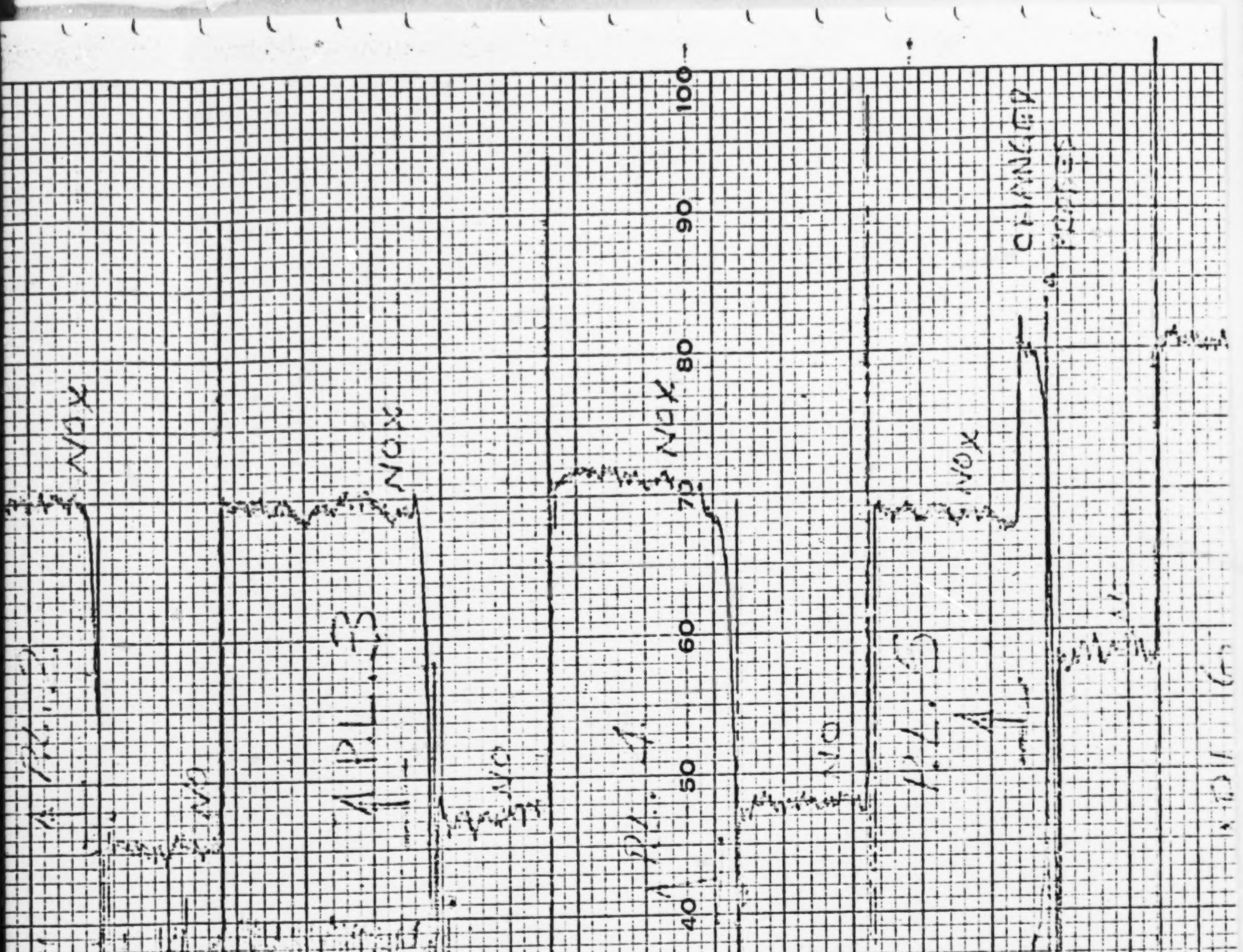
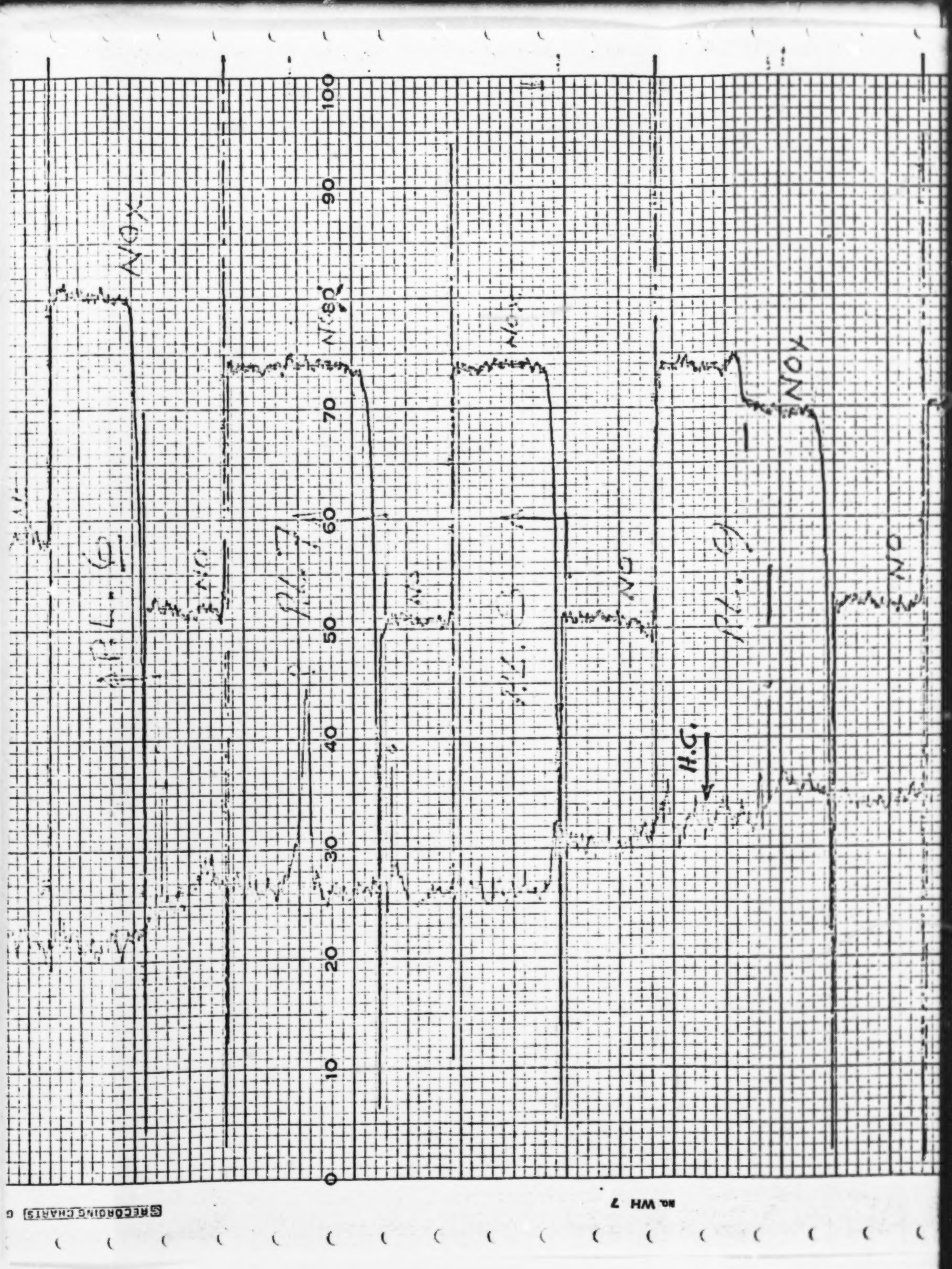
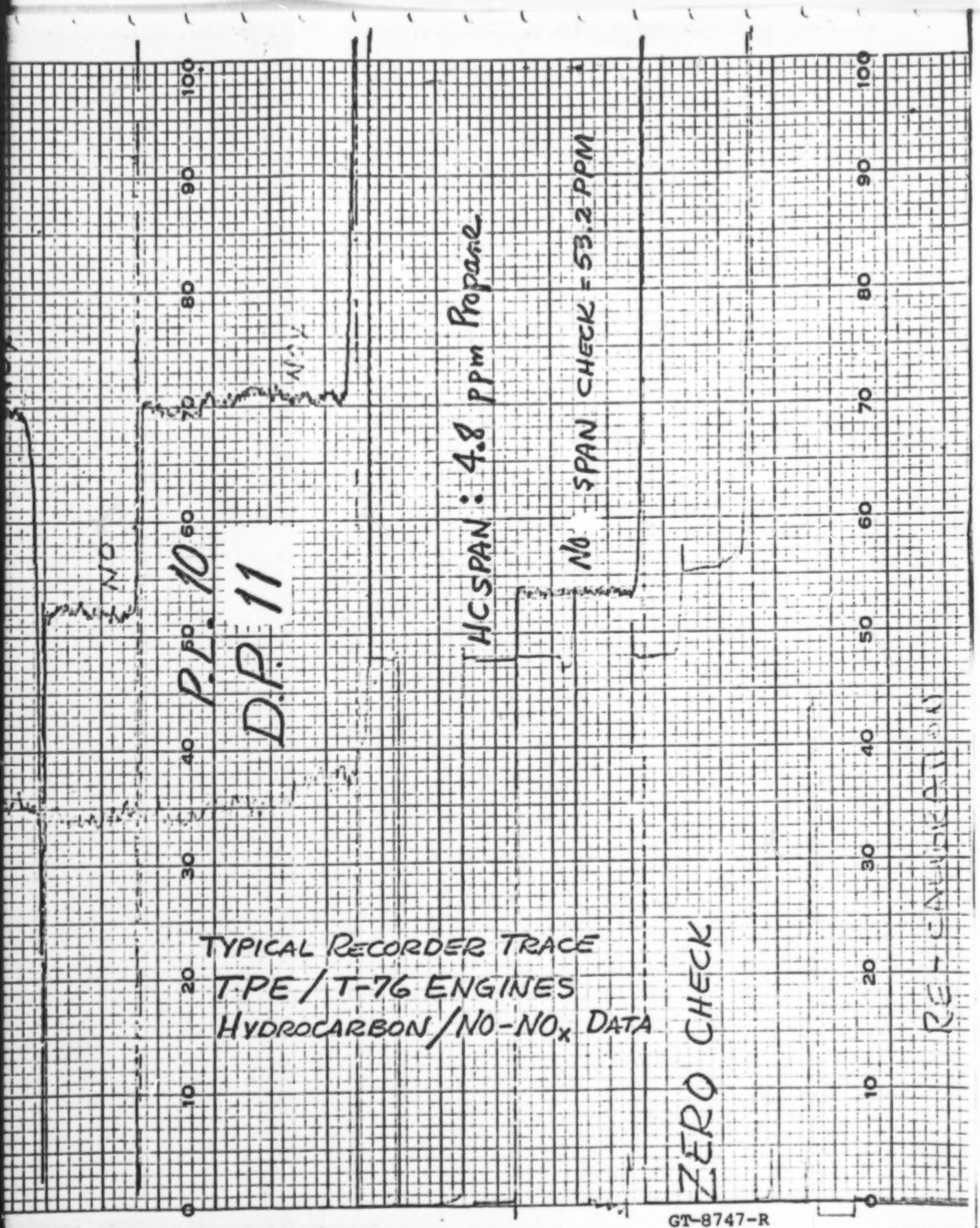
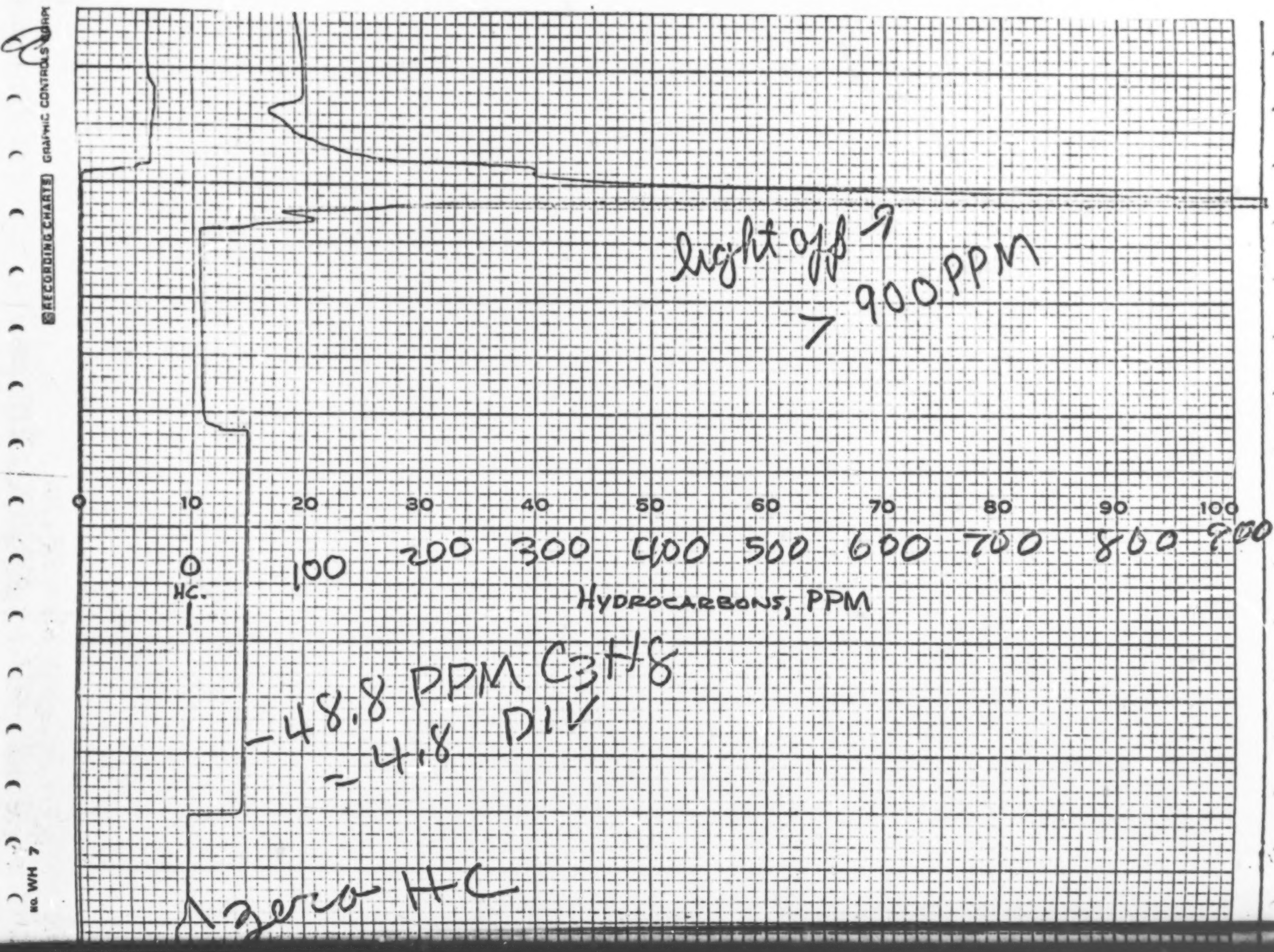


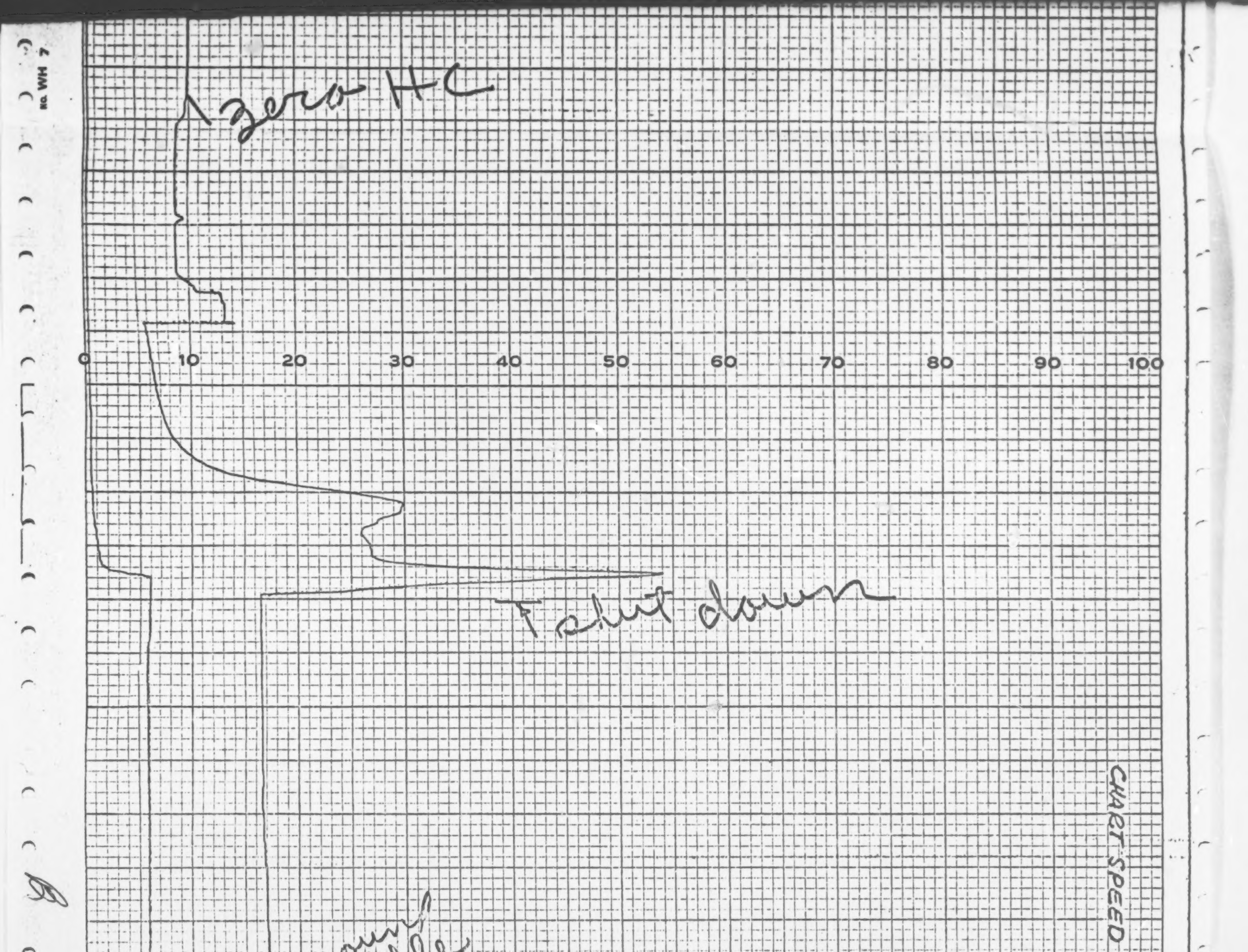
CHART SPEED:
1.5 inches/minute
APL 2
NOX
NO
APL 3
NOX
NO
APL 4
NOX
NO
APL 5
NOX
CHANGED RANGE
APL 6
0
10
20
30
40
50
60
70
80
90
100
GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK

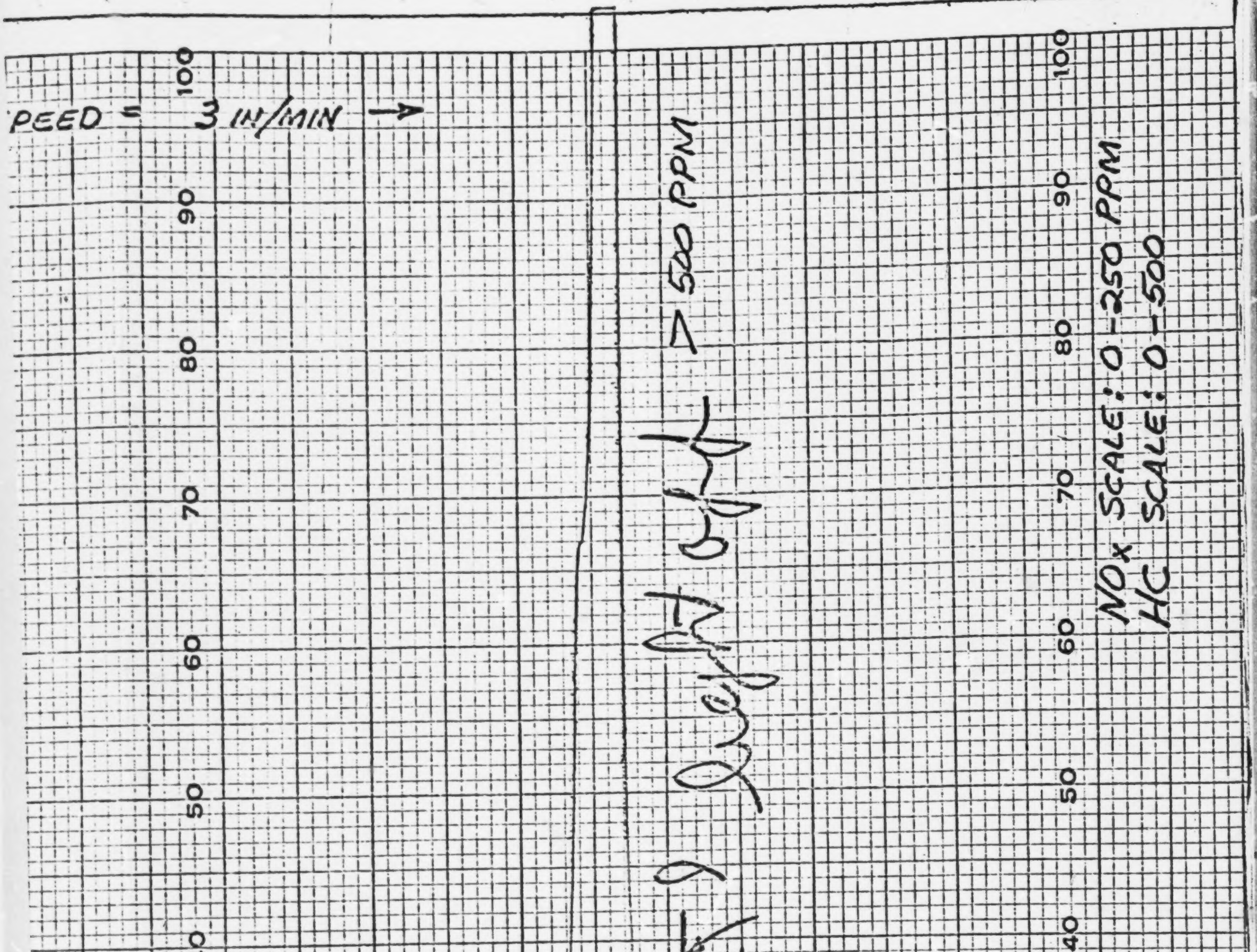

0
10
20
30
40
50
60
70
80
90
100
NOx
NO
Rl. 6
Rl. 7
Rl. 8
Rl. 9
H.C.
RECORDING CHARTS
No. WH 7



TYPICAL RECORDER TRACE
TPE/T-76 ENGINES
HYDROCARBON/NO-NO_x DATA

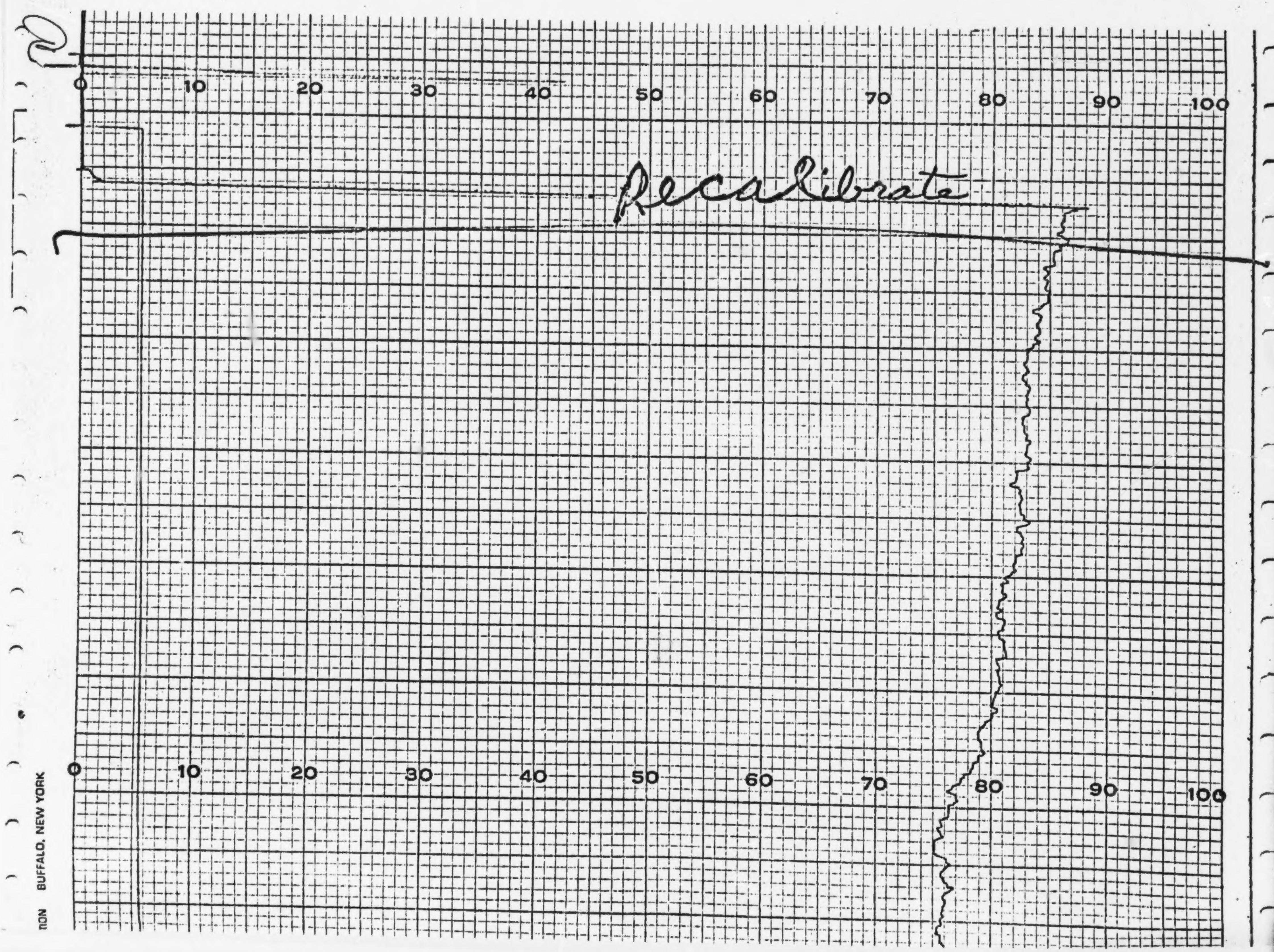

RECORDING CHARTS GRAPHIC CONTROLS CORP
NO. WH 7
0
10
20
30
40
50
60
70
80
90
100
0
HC.
100
200
300
400
500
600
700
800
900
HYDROCARBONS, PPM
light off ↗
> 900 PPM
-48.8 PPM C3H8
-4.8 DIV
zero HC

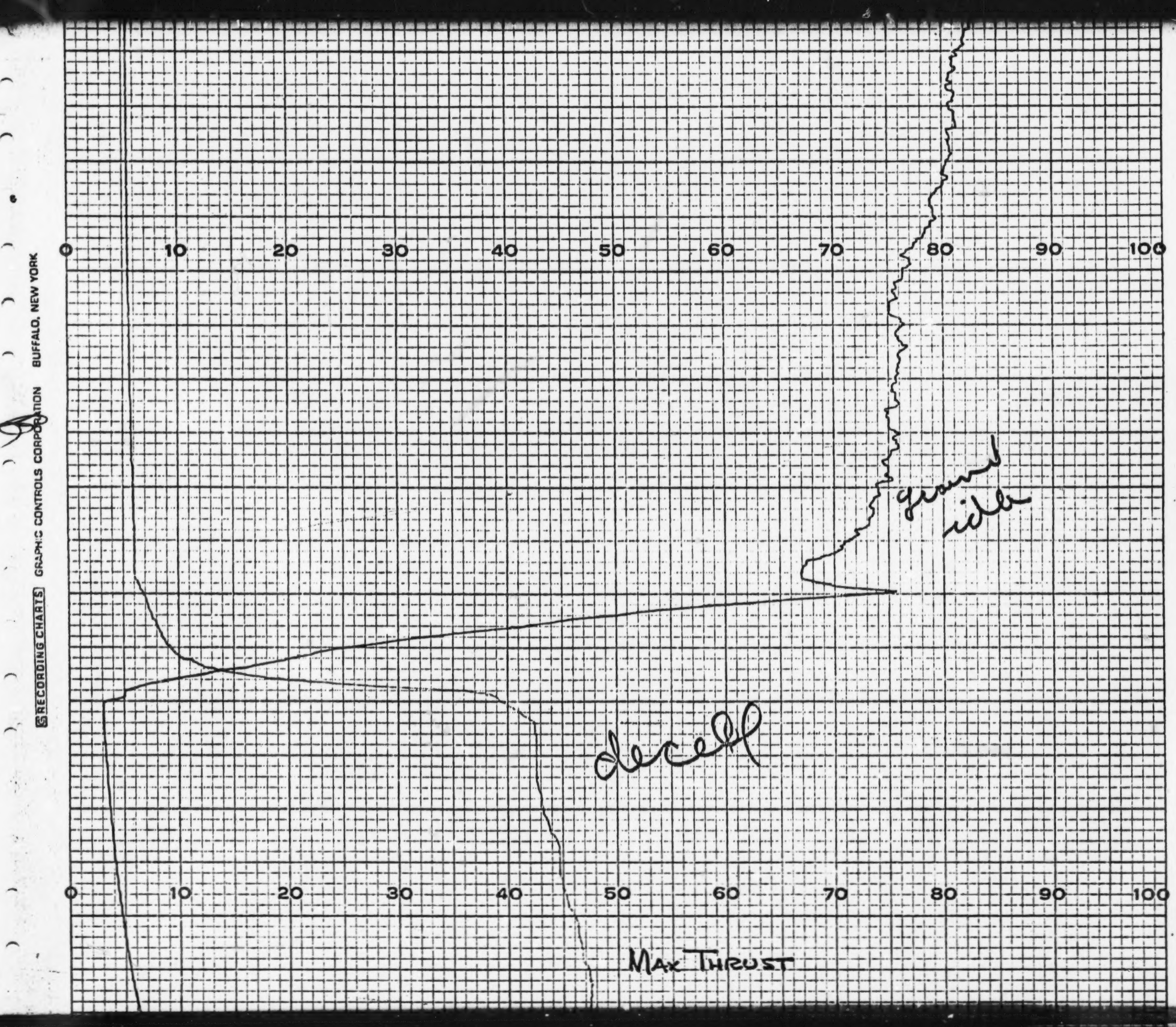

NO. WH 7
Zero HC
0
10
20
30
40
50
60
70
80
90
100
T shut down
CHART SPEED
B

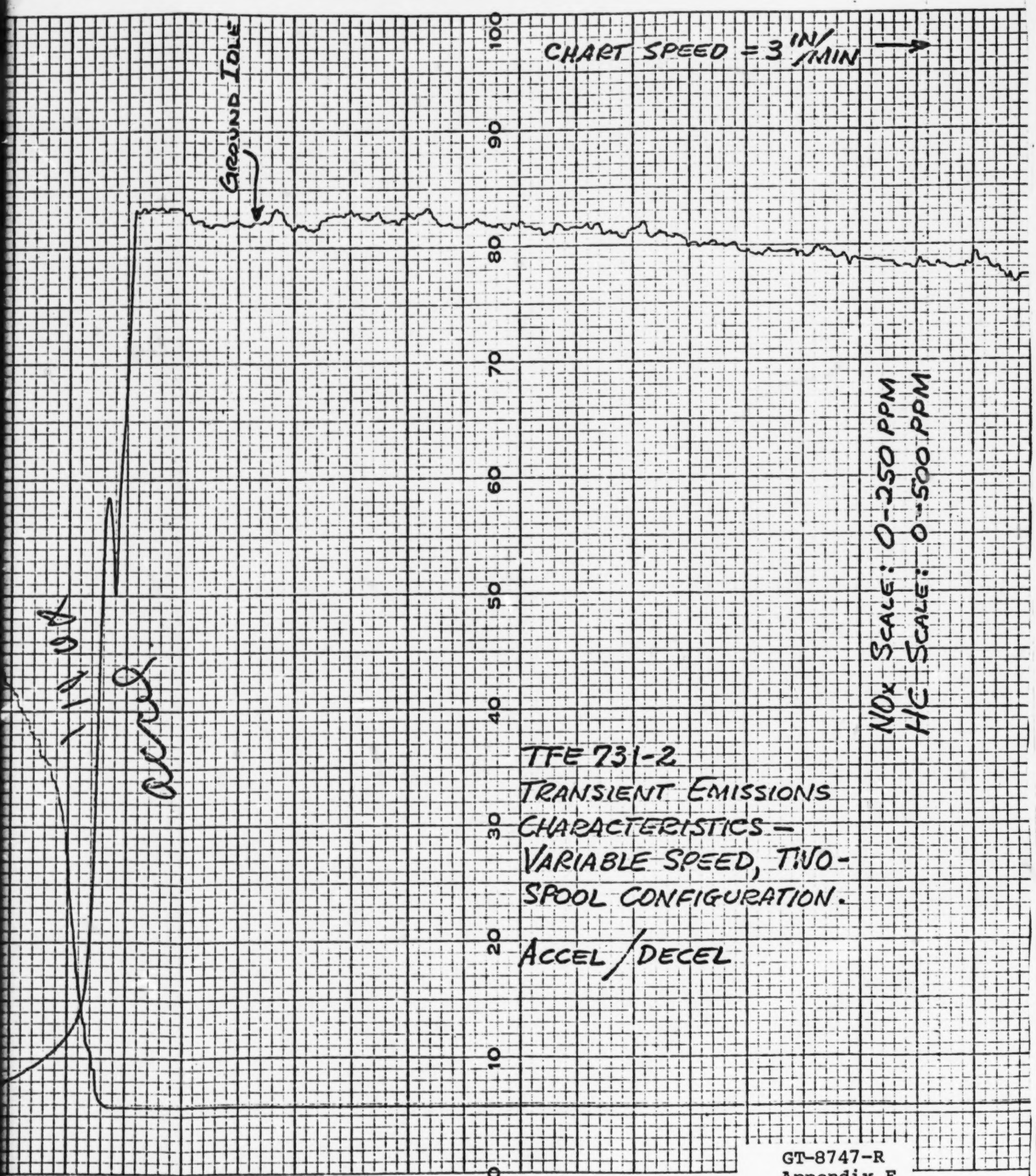


TFE 731-2
TRANSIENT EMISSIONS CHARACTERISTICS –
VARIABLE SPEED, TWO-SPOOL CONFIGURATION.
START/SHUTDOWN

C

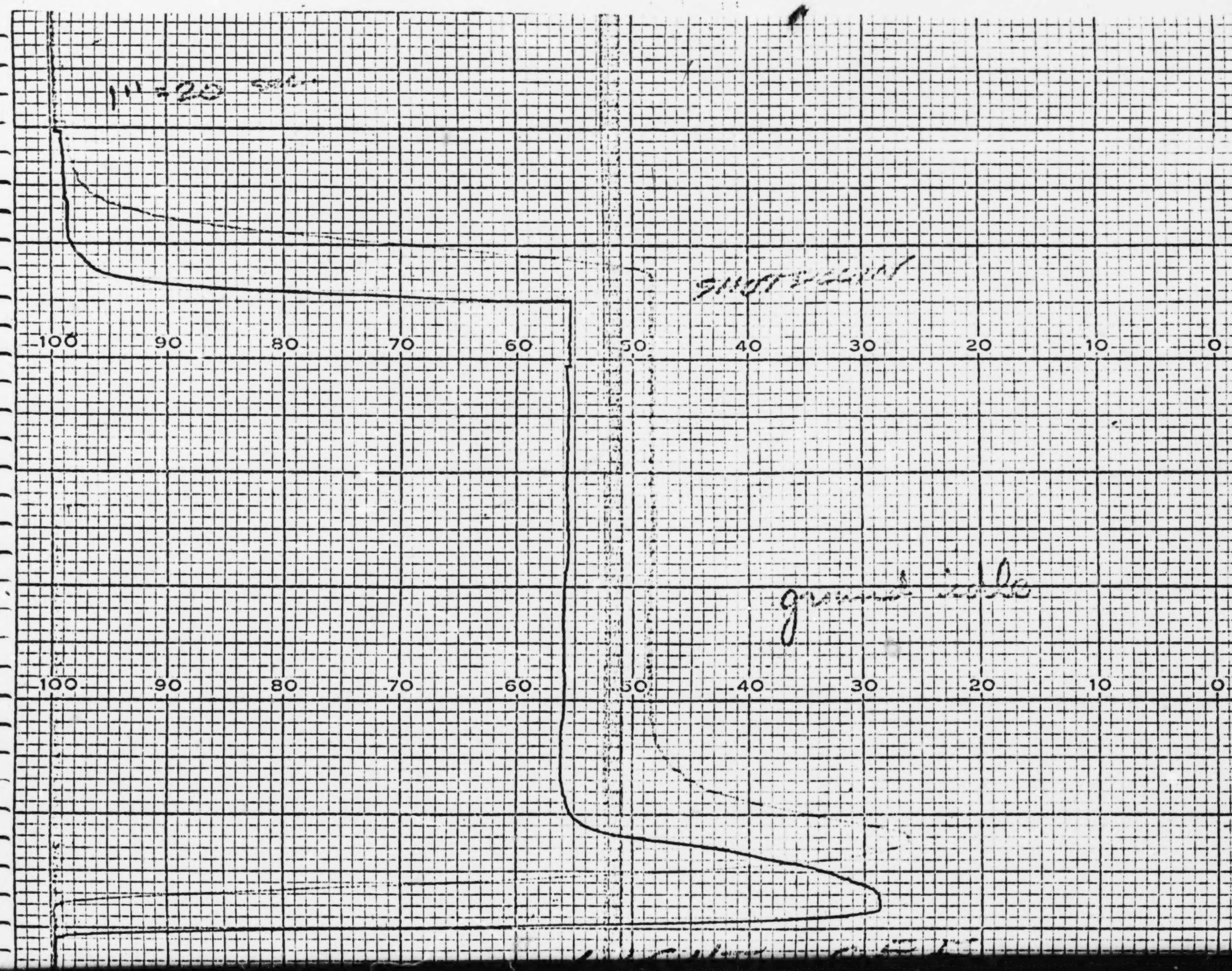

a
0
10
20
30
40
50
60
70
80
90
100
Recalibrate
0
10
20
30
40
50
60
70
80
90
100
BUFFALO, NEW YORK

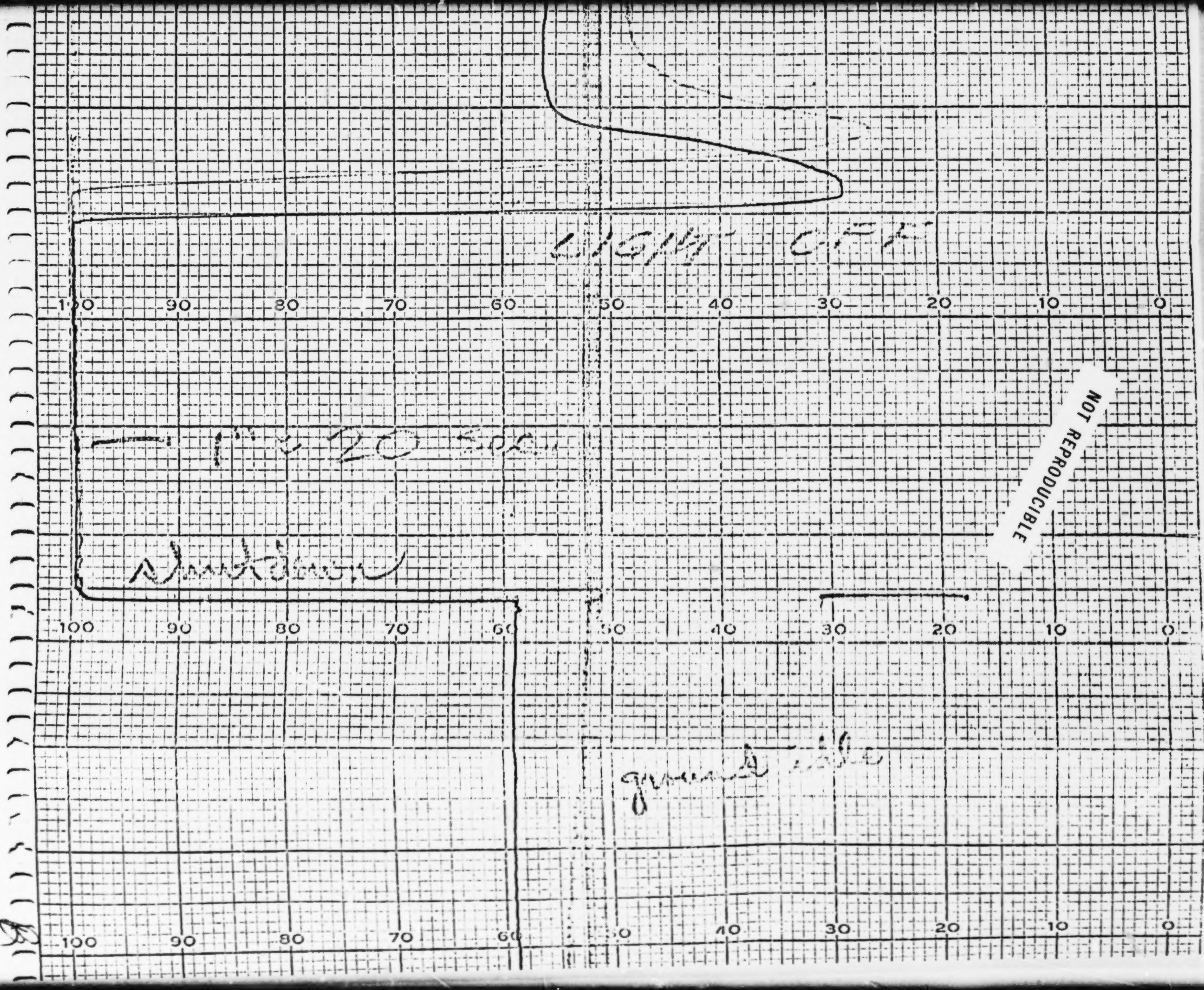
RECORDING CHARTS GRAPHIC CONTROLS CORPORATION BUFFALO, NEW YORK
0
10
20
30
40
50
60
70
80
90
100
ground idle
decel
MAX THRUST



TFE 731-2
TRANSIENT EMISSIONS CHARACTERISTICS — VARIABLE SPEED, TWO-SPOOL CONFIGURATION.

ACCEL/DECEL


1" = 20 sec
Shutdown
ground idle
100
90
80
70
60
50
40
30
20
10
0



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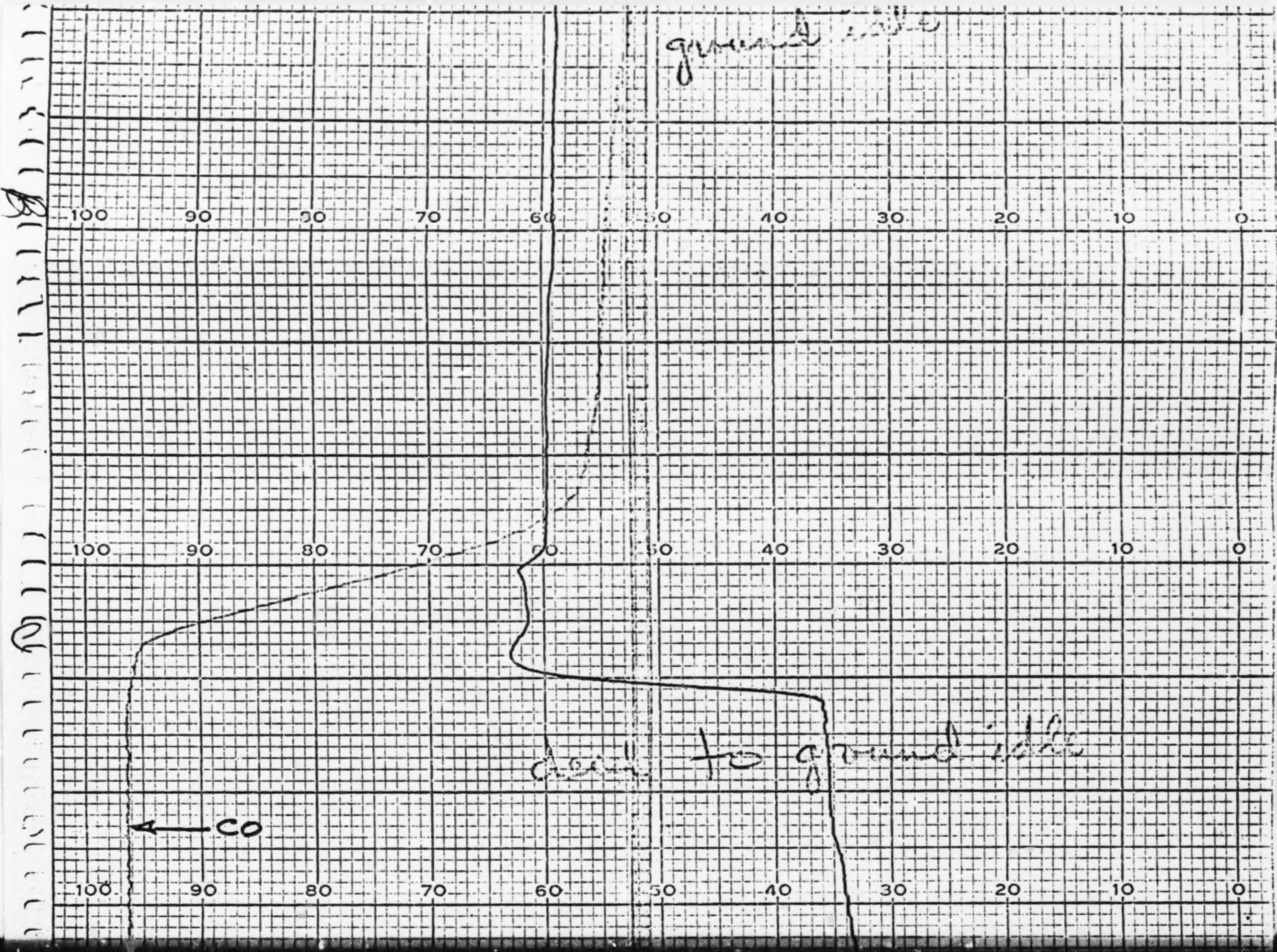
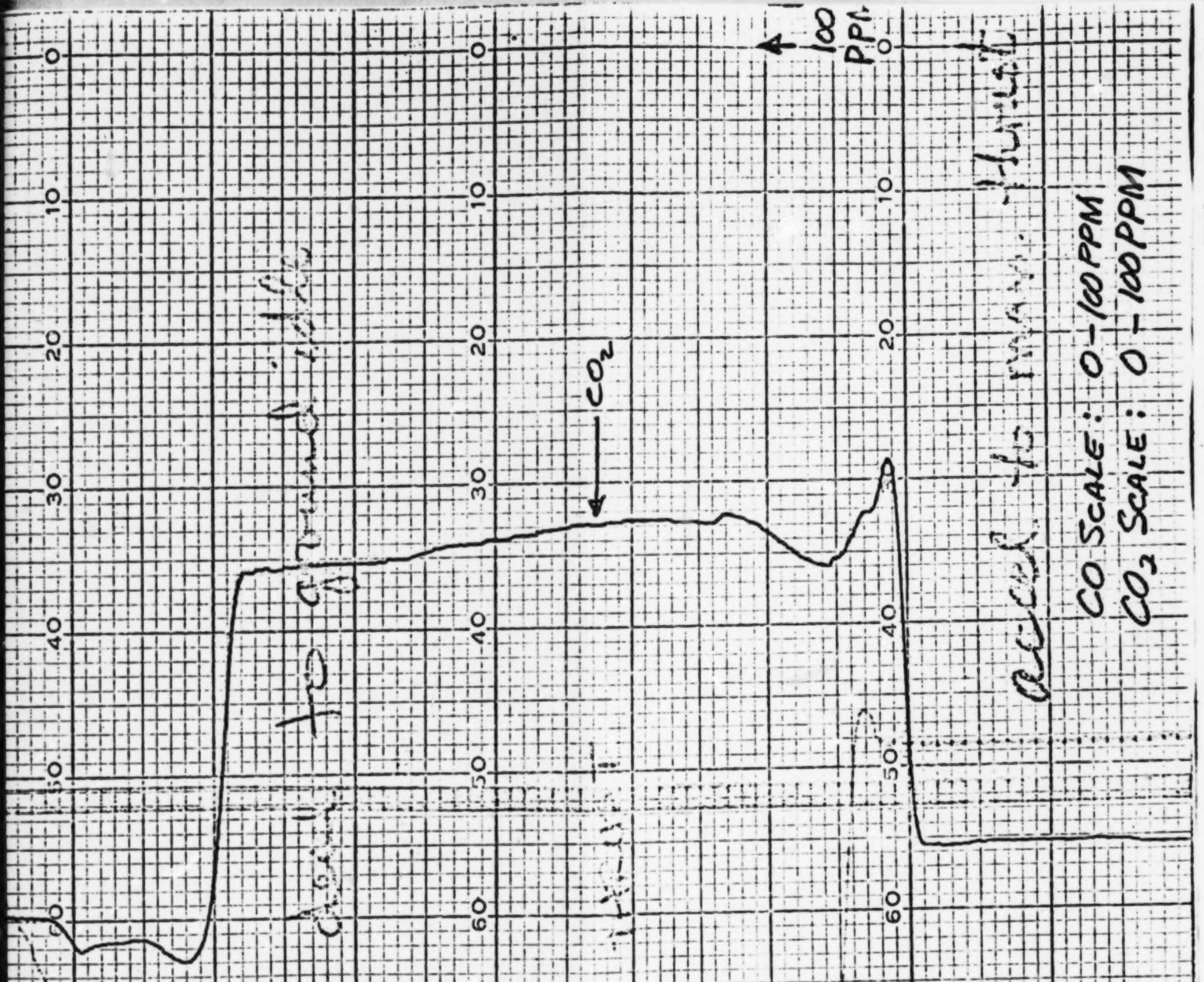

ground idle
B
100
90
80
70
60
50
40
30
20
10
0
C
decel to ground idle
← CO



TFE 731-2
TRANSIENT
EMISSIONS
CHARACTERISTICS
VARIABLE SPEED
TWO-SPOOL
CONFIGURATION

DATE
FILMED
1-11-72

PB 204 720

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